DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-23

HABITAT DEVELOPMENT FIELD INVESTIGATIONS WINDMILL POINT MARSH DEVELOPMENT SITE JAMES RIVER, VIRGINIA

APPENDIX F: ENVIRONMENTAL IMPACTS OF MARSH DEVELOPMENT WITH DREDGED MATERIAL: SEDIMENT AND WATER QUALITY

Volume II: Substrate And Chemical Flux Characteristics Of A Dredged Material Marsh

by

Donald D. Adams

Department of Chemistry, Wright State University, Dayton, Ohio 45431

Dennis A. Darby and Randolph J. Young

Department of Physics and Geophysical Sciences and Institute of Oceanography

Old Dominion University, Norfolk, Virginia 23508

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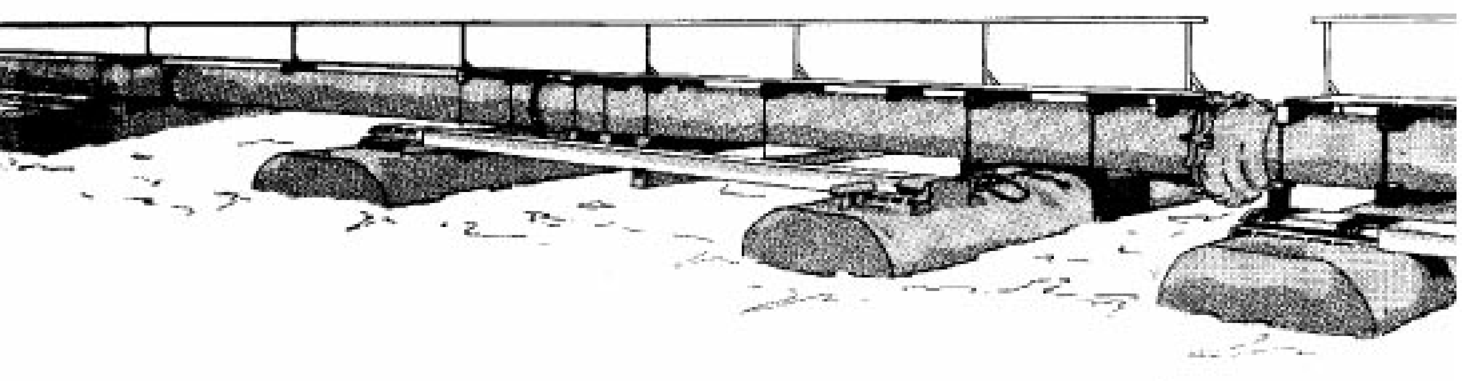

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P. O. Box 631, Vicksburg, Miss. 39180

HABITAT DEVELOPMENT FIELD INVESTIGATIONS, WINDMILL POINT MARSH DEVELOPMENT SITE, JAMES RIVER, VIRGINIA

Appendix A: Assessment of Vegetation on Existing Dredged Material Island

Appendix B: Propagation of Vascular Plants

Appendix C: Environmental Impacts of Marsh Development with Dredged Material: Acute Impacts on the Macrobenthic Community

Appendix D: Environmental Impacts of Marsh Development with Dredged Material: Botany, Soils, Aquatic Biology, and Wildlife

Appendix E: Environmental Impacts of Marsh Development with Dredged Material: Metals and Chlorinated Hydrocarbon Compounds in Marsh Soils and Vascular Plant Tissues

Appendix F: Environmental Impacts of Marsh Development with Dredged Material: Sediment and Water Quality

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P. O. BOX 631
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO: WESEV

13 October 1978

SUBJECT: Transmittal of Technical Report D-77-23, Appendix F (Volume II)

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of one of a series of research efforts (work units) undertaken as part of Task 4A (Marsh Development) of the Corps of Engineers' Dredged Material Research Program. Task 4A was part of the Habitat Development Project (HDP) and had as its objective the development and testing of the environmental, economic, and engineering feasibility of using dredged material as a substrate for marsh development.

2. Marsh development using dredged material was investigated by the HDP under both laboratory and field conditions. The study reported herein (comprising Work Units 4A11D, G, and H) was an integral part of a series of research contracts jointly developed to achieve Task 4A objectives at the Windmill Point Marsh Development Site, James River, Virginia, one of six marsh establishment sites located in different geographic regions of the United States. Interpretation of this report's findings and recommendations is best made in context with the other reports in the Windmill Point site series (4A11A-M).

3. This report, "Appendix F: Environmental Impacts of Marsh Development with Dredged Material: Sediment and Water Quality" appears in two volumes and is one of six contractor-prepared appendices published relative to the Waterways Experiment Station's Technical Report D-77-23, entitled "Habitat Development Field Investigations, Windmill Point Marsh Development Site, James River, Virginia; Summary Report" (4A11M). The appendices to the Summary Report are studies that provide technical background and supporting data and may or may not represent discrete research products. Appendices that are largely data tabulations or that clearly have only site-specific relevance were published as microfiche; those with more general application were published as printed reports.

WESEV 13 October 1978

SUBJECT: Transmittal of Technical Report D-77-23, Appendix F (Volume II)

4. Volume I was entitled "Characteristics of Channel Sediments Before Dredging and Effluent Quality During and Shortly After Marsh Habitat Development." Research described in that document included a chemical and physical evaluation of channel sediment characteristics before dredging and a chemical and physical evaluation of effluent at the habitat development site during active disposal, dewatering, and 3.5 months after disposal was complete. Volume II, entitled "Substrate and Chemical Flux Characteristics of a Dredged Material Marsh," is forwarded herewith. Research described in Volume II included documentation of changes in the physical and chemical properties of the developed marsh substrate and the longer term tidal flux characteristics of nutrient and metallic substances. The relationship between substrate conditions and chemical flux is discussed and all observations are compared with parallel studies conducted in a nearby natural marsh.

5. Data from this report will be included in the Windmill Point Summary Report (4A11M) and synthesized in Technical Reports DS-78-15 and DS-78-16, entitled "Upland and Wetland Habitat Development with Dredged Material: Ecological Considerations" and "Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation," respectively.

John L. Cannon

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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Appendices A' through E' were reproduced on microfiche and are enclosed in an envelope attached to the back cover of this volume.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Dredged material	Habitats	Sediment
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Freshwater marsh	Metal fluxes	Windmill Point
Habitat development	Nutrient fluxes	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This volume is the second of a two-volume appendix presenting the results of chemical and sedimentological studies conducted at a dredged material marsh development site located near Windmill Point, on the tidal freshwater James River, 16 km below Hopewell, Virginia.

Sediment and water quality studies conducted before, during, and shortly following dredged material disposal for marsh site construction are presented in Volume I. This volume presents results of substrate sediment studies conducted at the marsh development site and a natural reference marsh 6, 18, and 24 months after site construction. It also compares the physical and chemical transport characteristics of the two marshes based upon monitoring tidal water quality conditions 18 and 24 months following habitat development.

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20. ABSTRACT (Continued).

Sediment cores were collected and processed using techniques designed to document horizontal and vertical physical and chemical gradients and allow comparisons between sampling periods. Temperature, pH, redox potential, water and volatile solids content, particle size composition, mineralogy, cation exchange capacity, and interstitial and total concentrations of nutrients, carbon, and metals were studied. Metal associations with organic, easily and moderately reduceable and residual sediment phases were also examined.

Comparisons between the marsh development site and the natural reference marsh substrate indicated that the reference marsh was more acidic (pH = 6.2 versus 6.7), slightly more oxidized (Eh = +150 versus +115 mV), and contained finer mean size (2 versus 6 μm) and more organic (percent volatile solids - 16 versus 7.5) sediments with higher cation exchange capacity (60 versus 32 meq/100 g). Interstitial and total nutrient and carbon levels in both marshes were similar with a few exceptions. Total Kjeldahl nitrogen in the experimental marsh sediments was lower than levels in the natural marsh. Changes in total Kjeldahl nitrogen concentration appeared to be related to losses during dredging, oxidation losses, and plant uptake of demineralized nitrogen forms. Seasonal changes in sediment pore water levels of dissolved total nitrogen, organic carbon, calcium, iron, and mercury were indicated. Pore water values of dissolved iron and manganese increased during the 18-month period following marsh construction.

Water quality studies were conducted during 48-52 hour tidal sampling programs in August 1976 and January 1977. Temperature, dissolved oxygen, turbidity, pH, alkalinity, and dissolved nutrients, carbon, metals, and other variables were studied. Seasonal mass chemical transport was calculated using topographic and tidal volume data for both marshes.

Analysis of variance identified thirteen variables that were different between both marshes in August and January. Eight were higher at the experimental site: conductivity, total phosphorus, turbidity, orthophosphate, nitrate plus nitrite, calcium, manganese, and volatile organic carbon. Two were higher at the reference marsh: pH and dissolved oxygen.

Mass transport calculations (in units of kg/tidal cycle) for the experimental marsh in August 1976 identified the export of dissolved volatile organic carbon (15), dissolved organic carbon (14), dissolved total nitrogen (8.7), particulate iron (3.4), and dissolved calcium (3.3). Suspended solids (18), dissolved oxygen (14), and total Kjeldahl nitrogen (4) were imported during this period. In January 1977, dissolved organic carbon (15) and dissolved volatile organic carbon (6) were exported while suspended solids (44), total Kjeldahl nitrogen (3.9), particulate iron (3.7), and dissolved total nitrogen (2.4) and dissolved calcium (2.3) were imported.

Similar calculations for reference marsh transport identified the August 1976 export of total Kjeldahl nitrogen (73), dissolved organic carbon (69), suspended solids (36), dissolved volatile organic carbon(36), dissolved calcium (26), dissolved oxygen (18), particulate iron (6.1), dissolved nitrate plus nitrite (4.3), dissolved iron (2.0), dissolved zinc (1.0), and dissolved manganese (0.9). Dissolved total nitrogen (18) and ammonium (3.3) were imported. In January 1977, the largest measurable exports included dissolved organic carbon (40), dissolved total nitrogen (29), dissolved total Kjeldahl nitrogen (7.3), and ammonium (4.8). Numerous variables, including suspended solids (40), dissolved calcium (37), dissolved volatile organic carbon (22), particulate iron (21), dissolved oxygen (19), particulate calcium (2.3), and particulate manganese (0.8), were imported to the reference marsh in January 1977. The continuous export of dissolved manganese from both marshes in August and January was offered as an explanation for the lower sediment manganese levels of the older natural marsh at 330 μg/g versus experimental marsh values of 900 μg/g.

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PREFACE

This report contains the results of investigations of the chemical and sedimentological characteristics of the James River Artificial Habitat Development Site and a reference marsh near Windmill Point, Virginia. Studies were conducted in the channel before dredging and during site construction as well as at specific time intervals after marsh development. This study forms a part of the Dredged Material Research Program (DMRP), Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, and was conducted under contracts DACW65-75-C-0051 and DACW65-76-C-0039 with the Old Dominion University Research Foundation, Old Dominion University (ODU), Norfolk, Virginia. Contracting was handled by the U. S. Army Engineer District, Norfolk (NAO); LTC R. H. Routh, CE, NAO, was the Contracting Officer.

Dr. Donald D. Adams,* Institute of Oceanography, ODU, was the principal investigator and supervised the field program and chemical studies. Dr. Dennis A. Darby, Department of Physics and Geophysical Sciences, conducted the geological and sedimentological studies, while Randolph J. Young, Institute of Oceanography, was responsible for the metals program. Dr. Robert LaBudde and J. A. Menchhoff, ODU, developed statistical routines for ANOVA and mass transport, respectively. Research assistants for this study were A. S. Katsaounis, W. T. Nivens, D. L. Stealey, and C. L. (Pomeroy) Young. Part-time help was provided by G. Adams and P. Crowley. Computer programs were developed by P. J. Anninos, J. A. Menchhoff, and L. E. Whitlock. Numerous students participated in both the field operations and laboratory analysis. The utilization of laboratory and cold room facilities at the Department of Chemistry, ODU, was greatly appreciated. Close cooperation with NAO, especially with Mr. E. E. Whitehurst, was especially helpful. The cooperation of the captain and crew of ODU's vessel LINWOOD HOLTON is gratefully

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* Present address: Department of Chemistry, Wright State University, Dayton, Ohio 45431.

acknowledged. Mr. David Harrison, Flowerdew Hundred Farm and Windmill Point Island, cooperated by allowing use of his facilities and access to the experimental site.

This work was conducted under the direction of EL personnel. The study was designed by John D. Lunz, Natural Resources Development Branch, in close cooperation with the principal investigators. The contract was managed by Mr. Lunz under the supervision of Dr. W. Gallaher, Branch Chief, and Dr. C. J. Kirby, Chief, Environmental Resources Division. The study was under the general supervision of Dr. H. K. Smith, Habitat Development Project Manager, and Dr. J. Harrison, Chief, EL. Directors of WES during the conduct of the study were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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** Appendices A' through E' were reproduced on microfiche and are enclosed in an envelope attached inside the back cover of this volume.

HABITAT DEVELOPMENT FIELD INVESTIGATIONS
WINDMILL POINT MARSH DEVELOPMENT SITE
JAMES RIVER, VIRGINIA

APPENDIX F: ENVIRONMENTAL IMPACTS OF MARSH DEVELOPMENT WITH DREDGED MATERIAL: SEDIMENT AND WATER QUALITY

VOLUME II: SUBSTRATE AND CHEMICAL FLUX CHARACTERISTICS OF A DREDGED MATERIAL MARSH

PART I: INTRODUCTION

Background

1. In 1973 the Dredged Material Research Program (DMRP) of the U. S. Army Engineer Waterways Experiment Station (WES) was established to address environmental and technical alternatives for the disposal of dredged sediments from the Nation's waterways. One of the major programs under the DMRP was the Habitat Development Project (HDP), which was designed to evaluate and demonstrate potential fish and wildlife habitat development as a disposal alternative. Because of substantial loss of wetlands in the past decades, the major thrust of the HDP was toward the development of marshes from dredged material. Eight marsh development study locations were established throughout the United States. The Windmill Point site, located on the James River about 16 km downstream from Hopewell, Virginia, was one of these studies.

2. Shoaling on the James River has been a major problem to safe navigation and transport of cargo to the ports of Hopewell and Richmond (U. S. Army Engineer District, Norfolk 1974). As early as 1870, Congress approved the excavation of a channel between Richmond and Newport News (Pleasants 1973). Portions of the Jordan Point-Harrison Bar-Windmill Point shoal, located approximately 93 km upstream of the river's mouth and the harbor of Hampton Roads, require annual main-

tenance. Biannual dredging of approximately 222,000 m^3 from this 13-km channel and the subsequent open-water side channel disposal of the dredged material resulted in filling of the river bottom and the creation of a small 0.6-ha island south of the channel upstream from Windmill Point. The Windmill Point marsh development site, hereafter referred to as the "development site" or "artificial habitat," was established in early 1975 in shallow waters on the upstream side of this preexisting 0.6-ha island composed of dredged channel sediments.

3. The U. S. Army Engineer District, Norfolk, and the Environmental Laboratory (EL) at WES developed this artificial marsh-island complex as part of the normal maintenance dredging program of the navigational channel. Approximately 62,300 m^3 of sand was pumped from a borrow area near Buckler's Point to construct retaining dikes for the artificial marsh (Figure 1 in Volume I).* Between 21 January and 4 February 1975, approximately 166,540 m^3 channel sediments were pumped into the 6.1-ha rectangular (396 by 152-m) site (Table 1 in Volume I) to provide an average fill depth of 1.1 m. All dredged channel sediments entered the rectangular diked area at its northwest corner; the dredged material slurry traveled approximately 425 m within the dike before reaching the unrestricted effluent discharge point located at the dike's southeast corner and consisting of two 0.9-m diameter corrugated steel pipes. Following the completion of dredged material disposal activities, these effluent pipes along with a small breach that developed in the southern portion of the dike served as entry and exit locations for regular tidal influence on the experimental substrate. Before and after site development, extensive studies were conducted by the HDP to document the chemical, biological, and geological alterations related to this marsh habitat development project.

4. The objectives of studies reported in the first volume of this appendix were: (a) to document the chemical and sedimentological nature of the channel sediments before dredging, (b) to relate these findings to effluent water quality at the development site during dredging, and

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* Figures 1 to 6 and Tables 1 to 25 appear in Volume I.

(c) to document the mobilization of selected potential pollutants from the recently dredged substrate to the river water in the short term following site construction. Additional sediment and water-quality investigations were conducted at the Windmill Point development site and at a reference marsh after site construction was completed. These additional studies were designed to contrast the physical and chemical characteristics of the substrate and tidal waters at the two marshes. The results of these studies comprise the second volume of this appendix entitled, "Substrate and Chemical Flux Characteristics of a Dredged Material Marsh."

5. Field studies were undertaken eight different times at the site over a period of 2 years to investigate conditions during and after marsh development. The first six field collections were conducted at the development site only and provided the data discussed in Volume I. The last two field collections included observations at both the development site and reference marsh, situated 3.2 km upstream from the development site, near the mouth of Herring Creek at Ducking Stool Point (Figure 2 in Volume I); these data are presented in Volume II. Data interpretation emphasized the relationships between the chemistry and geology of fine-grained sediments, the change in the chemistry and geology of the sediments and river water related to a specific dredged material disposal alternative and the establishment of a freshwater marsh habitat. Results of these studies are applicable to Corps of Engineer (CE) projects requiring an understanding of: (a) the chemistry and geology of fluvial-estuarine sediments in areas of rapid desposition, and (b) the chemical budgets in freshwater marsh ecosystems.

Approach and Chronology

6. Ten sediment cores were taken along a 1.5-km section of the navigational channel of the Jordan Point-Harrison Bar-Windmill Point shoal before dredging in January 1975. The effluent from the intertidal habitat containment area was sampled every 6 hours at one of the effluent pipes during four 48-hr periods: once during dredging (31

January to 1 February 1975); again during the dewatering period (6-8 February 1975), two days after dredging had ceased; and two additional 48-hr periods on 18-20 April and 13-15 May 1975, approximately 2.5 and 3.5 months after dredging, respectively. Because of unusual weather conditions in April, when high winds prevented tidal water from entering the diked intertidal habitat, only the May sampling program will be reported. This information is provided in Volume I.

7. The last 48-hr field water-quality studies were conducted 18 (5-7 August 1976) and 24 months (8-10 January 1977) after dredging. These two programs were the most extensive of the field operations and were chosen to represent different seasons. Sediment studies were conducted by coring three different locations (subtidal, intertidal, and high marsh) at the development site on three different occasions during July 1975 (6 months after dredging), August 1976 (18 months after dredging), and January 1977 (24 months after dredging). The reference marsh was sampled at corresponding locations during August 1976 and January 1977. At each of these locations, cores were collected within a 25-m^2 quadrant for a total of nine cores from each marsh for each period (Figures 2 and 3 in Volume I). Sediments from these cores were divided into specific depth intervals of 0 to 10 cm (surface), 11 to 24 cm (mid-depth), and 25 to 50 cm (deep). In addition, surface sediment grab samples and cores were collected within the development site in July 1976 (17 months after dredging) and July 1977 (29 months after dredging) for special studies (Table 2 in Volume I, Table 26).

8. A listing of the various parameters examined throughout this study is presented in Table 2 (Volume I). Data plots for each of the parameters are presented in Appendix A'; data tabulations are presented in Appendix B'. Sediment and tidal statistics are listed in Appendix B'.

Physical Setting

9. Windmill Point is located on the James River approximately 51 km below Richmond, Virginia, and 93 km above the harbor of Hampton Roads. Slightly upstream of Windmill Point is the Jordan Point-

Harrison Bar-Windmill Point shoal located between Buckler's and Windmill Point (Figure 1 in Volume I). Portions of the channel associated with this shoal require annual maintenance dredging and experience an overall sedimentation rate in the channel of about 90 cm/yr. This specific portion of the channel was last dredged two years prior to being used for habitat development. A description of this section of the river is provided in Table 1 (Volume I). Only 16 km upstream of Windmill Point is the industrial city of Hopewell, which discharges effluent containing an average of 36,000 kg/day biochemical oxygen demand (BOD) (Diaz and Boesch 1977). Major manufacturing activities at Hopewell are chemicals, paper products, fertilizers, and synthetic fibers. Effluents from these industrial activities probably contribute to historical indications that bottom sediments near Windmill Point exceeded Environmental Protection Agency criteria for open-water disposal of dredged materials due to levels of chemical oxygen demand (COD), volatile solids, total Kjeldahl nitrogen (TKN), lead, and zinc.

10. Previous salinity data for the study area, which is part of the lower tidal freshwater James, indicated the absence of salt water during 1968 and 1969 (Brehmer 1972), yet it was suggested by Diaz and Boesch (1977), based on benthic faunal data, that during drought conditions in the mid-1960's, intrusion probably occurred as far upstream as Hopewell. Salinity typically does not exceed 2 o/oo at Swann's Point located 30 km downstream of Windmill Point. Tidal currents of 0 to 80 cm/sec, with a normal range of 20 cm/sec, were reported for a section of the James River 20 km below the study area (Nichols 1972). The mean annual river discharge was approximately 212 m^3/sec with recorded extremes of 0.3 to 9,200 m^3/sec.

Water quality

11. One of the three major BOD peaks on the James River was reported near and below Hopewell (James River Comprehensive Water Quality Management Study 1972), where oxygen depression was a common occurrence in the summer. Dissolved nitrate-N was as high as 2 mg/ℓ for the waters of the study area, while dissolved inorganic orthophosphate-P reached concentrations of 0.6 mg/ℓ during October for this stretch

of the river. Brehmer (1972) reported a mean pH of about 7.7, with a range of 6.8 to 8.6, for the freshwater section of the James River, while suspended solids concentrations ranged between 29 to 44 mg/ℓ with approximately 19 to 31 percent consisting of volatile matter (Brehmer and Haltiwanger 1966). Further data are provided in Table 3 (Volume I).

Sediment quality

12. The redox potential of the James River channel sediments ranged from -70 to +50 mV within the top 18 cm, while the interstitial pH was reported as 6.7 for two stations near the study area (Moncure and Nichols 1968). At stations below Windmill Point, these authors reported organic matter content varying between 0 and 4 percent. Analyses of channel sediments near Windmill Point indicated 10 percent volatile solids, 9 percent chemical oxygen demand (COD), 2,190 ppm total Kjeldahl nitrogen (TKN), 53 ppm lead, 0.3 ppm mercury, and 260 ppm zinc (U. S. Army Engineer District, Norfolk 1974). Other data (Lunz and Huggett 1974) gave values of 464 ppm total phosphorus, 28 ppm total copper, and 49 percent total solids. Further data are listed in Table 3 (Volume I).

13. Previous analyses of sediment particle size or cation exchange capacity have not been reported for the Windmill Point area. The lower 77-km section of the James River contains silty clay or sand, or a mixture of sand-silt-clay with an average of 39 percent clay (Moncure and Nichols 1968, Nichols 1972). These authors also reported a general decrease in sediment size sorting and water content from the estuary mouth upstream and from dredged channels to the shoals.

14. Quartz and feldspar dominated the sand-size sediment, with lesser amounts of fecal pellets, plant debris, heavy minerals, mica, coal fragments, fly ash, and cinder (Nichols 1972). Calcium carbonate contents of the sediments decreased from 41 percent at the mouth of the James River to 2 percent 77 km upstream. Nichols (1972) also reported that the clays consisted of 44 percent illite, 24 percent chlorite, 18 percent smectite, and 15 percent kaolinite in the vicinity of Hopewell, with decreasing amounts of smectite and illite downstream, while Feuillet (1976) listed 33 percent kaolinite, 30 percent mixed-

layered clays, 20 percent illite, 12 percent vermiculite, less than 5 percent chlorite, and 3 percent smectite for the same area of the river. Because clay minerology values are imprecise and normally vary by ±15 to 20 percent, the only real difference between these two reports was the identification of vermiculite and mixed-layered clays by Feuillet (1976).

PART II: CHARACTERIZATION OF SUBSTRATES AT THE JAMES RIVER ARTIFICIAL HABITAT DEVELOPMENT SITE AND A REFERENCE MARSH

Introduction

Purpose

15. Because the geological and chemical characteristics of the sediment and its interstitial water are important to plant growth and to the mobilization of contaminants, the same parameters that were measured in the James River channel sediments were monitored at both the development site and the reference marsh in August 1976 and January 1977. Comparisons of observations at the development site with those at the reference marsh allowed the identification of temporal changes unique to the contained dredged material.

Physical setting

16. The development site. Approximately 166,500 m^3 of James River channel sediments were pumped into the development site during the winter of 1975. This material flowed diagonally across the rectangular containment area (6.1 ha), and an estimated two-thirds exited through the outlet pipes forming a delta approximately half the size of the diked area. The sediment deposited inside the dike averaged about 1.1 m in thickness. Tidal flow through the pipes developed channels that extended about two-thirds the distance across the development site and paralleled the flow pattern of the dredged material slurry disposal into the containment area. A breach that occurred in the sand dike near its southeast corner (Figure 3 in Volume I) within 3 months after dredging served as a major tributary for tidal influence within the containment area. These tidal channels within the development site were 5 to 20 cm deep except at the pipes and breach. About two-thirds of the containment area was flooded by normal high tides with approximately 20,000 to 40,000 m^3 of water. Volunteer plant growth was evident in the spring of 1975 about 3 months after dredging and covered the diked substrate by July 1975. Only small clumps of dead vegetation and root systems remained during the winter months. In the first 2 years, the sand dikes

on the west, upstream side, of the site were gradually eroded, moving the highest elevation of the dike about 10 m to the east and over the edge of the dredged sediments inside.

17. The reference marsh. The tidal channels entering the reference marsh were about 2 m deep and 17 to 26 m wide. These channels formed a rectangular pattern immediately adjacent to Herring Creek (Figure 3 in Volume I) and are believed to have resulted from dike construction in the eighteenth century when rice was experimentally cultivated in this marsh. Near the center of the marsh, the tidal channels decrease in depth to less than 50 cm at low tide and become more sinuous and typical of natural tidal marshes. The reference marsh was similar to the development site in vegetation composition but was dominated by different plant species. The winter appearance of plants was similar at both sites but the reference marsh had a denser and deeper root system than was evident at the younger development site. Approximately 220,000 m^3 of water flooded the reference marsh during each tide, or about five or six times more volume than at the development site.

Methods and Materials

18. A total of 72 sediment cores and 19 surface grab samples were collected from the two marshes (Table 26 and Figures 2 and 3 in Volume I, and 7 and 8 in this volume). Cores were collected from three locations at each marsh corresponding to high marsh, intertidal, and subtidal zones for monitoring differences in values for total and interstitial dissolved metals, carbon, nutrients, sediment cation exchange capacity, sediment particle size, pH, Eh, pS, temperature, percent water, and percent volatile solids. Cores were collected from the same 25-m^2 locations at each marsh in August 1976 and January 1977 except for the intertidal and subtidal locations at the reference marsh where ice conditions blocked boat access in January 1977. This necessitated sampling near the channel banks, accessible overland, instead of midchannel locations. Cores were divided into surface (0 to 10 cm), middepth (11 to 24 cm), and deep (25 to 50 cm) horizons, except for July 1975 cores (see Appendix B' for

specific depth intervals). Analytical procedures were the same as those used for the James River channel sediment cores presented in Part II of Volume I except that most interstitial water parameters from the July 1975 cores were not analyzed for 17 to 19 months following collection, partially because of contractual delays. Interstitial ammonium and total H_2S concentrations were measured immediately after the July collection. Hydrogen sulfide was analyzed according to a modified method outlined in Goldhaber (1974). Interstitial water to be used for chemical measurements was acidified and frozen. The lengthy storage of the July 1975 collections precluded their analysis for interstitial mercury concentrations. Total calcium and chromium levels were analyzed by atomic absorption with a nitrous oxide-acetylene flame to minimize interferences; all other metals except mercury were analyzed with an air-acetylene flame. Cation exchange capacity was measured on unfractionated samples by sodium saturation and displacement by ammonium acetate (Chapman 1965) in order that results might be compared with other DMRP habitat development studies.

19. Samples for cation exchange capacity could not be analyzed immediately in all cases. A test on the effects of sealed storage in plastic bags at room temperature was made on two samples from the development site. These samples, analyzed in duplicate, decreased in cation exchange capacity by 23 $\pm$ 10 percent after storage for 13 months (Appendix B'). This decrease may have been due to a combination of organic matter decomposition and the visible formation of iron oxides and hydroxides, which could block exchange sites. Because of apparent storage effects on cation exchange capacity, values used in this report were from analyses conducted as soon as possible after collection, and at least within 6 months.

20. Possible effects of various centrifuge speeds on the concentrations of interstitial metals and nutrients were compared to concentrations obtained with a sediment squeezer (Presley et al. 1967). Significant changes in concentration were not observed with centrifugation above 9,000 and up to 15,000 rpm for 20 minutes at $4^{\circ}C$. For comparisons with centrifugation, a homogenized subsample was squeezed and fil-

tered with 100 psi (689 kilopascals) nitrogen. Dissolved calcium, manganese, and phosphate-P concentrations were slightly higher with centrifugation while iron concentrations were the same and zinc concentrations were lower than with squeezing. Dissolved nitrate and nitrite-N was higher by centrifugation; however, for the processing of numerous samples, centrifugation was the preferred procedure because of both speed and efficiency.

21. Digestion and drying procedures were also compared to determine the maximum recovery of total metals from the marsh sediments. Both oven drying at $60^{o}C$ and freeze drying were tested along with acid digestions at $60^{o}C$ and $95^{o}C$ for 1.5 and 5 hr, respectively. Freeze-drying followed by acid digestion at $95^{o}C$ for 5 hr provided the best recovery for the metals tested, with the exception of mercury, for which sediments were processed at the lower temperature. Metals associated with different fractions of the sediment were studied according to the method outlined in Engler et al. (1977).

22. Sediment samples for total water content and volatile solids content were collected in tared vials from the marsh surface adjacent to each core and from the bottom of each core. Sediment field vane shear measurements were made with a hand vane tester at depths of 23, 53, 84, 115, and 145 cm, or to depths that the vane no longer penetrated the substrate.

Results

Physical description of the marsh sediments

23. The sediment at the development site, as described from 11 split cores collected six months after deposition (Figure 7) was homogenous grayish brown silty clay with 1 to 10 percent black plant fragments (0.5 to 5 mm in dia.), 1- to 10-mm gas vesicles, and 1 to 10 percent mica flakes (0.05 to 2 mm) throughout. The dredged sediment was soupy from the surface to a depth of 10 or 20 cm. The original substrate was identified as a sharp contrast between dredged sediment and winnowed silt laminae. Below this 5- to 15-cm-thick interval of

winnowed laminae was homogenous sediment very similar to the dredged material above, but with indistinct layering. Sand layers were occasionally encountered in cores located near the sand dikes.

24. The sediment at the subtidal location in the middle of the reference marsh was similar in appearance to that of the development site. The only visible difference was occasional faint layering and mottling, the presence of plant roots in the upper 30 cm, and a greater consolidation with depth.

25. The water content values of the surface sediments 6 months after their deposition into the diked containment area were about the same as they were in the river channel (50 percent) before dredging (Table 27). In the reference marsh, the water content values were approximately 20 percent higher than those in the development site. Water content values did not change significantly at either marsh during the next 18 months. Both marshes exhibited an average decrease of 10 to 20 percent water from the surface to about a 65-cm depth.

26. While the water content did not change from the river channel sediments to the development site 6 months after deposition, the percent volatile solids at the surface (0- to 5-cm depth) decreased from 14.5 to 4.9 percent. By August 1976, following a period of luxuriant plant growth at the development site during the first summer, the volatile solids contents in the surface sediments increased to 10.9 percent (Table 27). This percentage decreased only slightly to 8.9 percent by January 1977. Percent volatile solids was higher in the reference marsh by an average of 8 percent and the change in percent volatile solids with depth was different at the two marshes. Values decreased with depth at the development site from a mean of 9.8 to 6.9 percent, while at the reference marsh there was a slight increase with depth (Appendix B'). Analysis of variance for percent water content and percent volatile solids among the three coring locations of each marsh identified differences for the surface percent water content between the different locations at both marshes and for the percent volatile solids at the coring locations of the reference marsh (Appendix B').

Chemistry of the marsh sediments

27. The sediment pH, which averaged 6.78 ± 0.35 during the first summer at the development site, was slightly higher, but not significantly different, than the James River channel (6.60 ± 0.22 pH; Table 27). This apparent difference was due to the higher pH values of 7.3 measured in the cores from the high marsh zone. Intertidal and subtidal marsh sediments averaged 6.54 in July 1975, about the same as the channel sediment. The pH changed very little during the next 1.5 years, averaging 6.41 ± 0.47 pH for the reference and artificial during August 1976 and January 1977. Also, the pH did not change substantially with depth (Appendix C') except for July 1975 cores, where the lower sections, with a higher percent water and lower pH and redox potentials as compared to the middle and upper sections of the cores, probably represented the previous substrate* before dredging. The sediments at the reference marsh were more acidic (usually by about 0.5 pH units) than those of the development site. Values for pH in the deep (25-50 cm) subtidal sediments of the reference marsh were lowest (5.3) in January 1977, and slightly more acidic than the lowest development site sediment pH value (5.8). Average pH values for both August 1976 and January 1977 were lowest (5.9) at the high marsh zone of the reference marsh; the highest average pH values (6.8) for both August 1976 and January 1977 were observed at the subtidal location of the development site.

28. Average redox potentials increased from -25 mV in the James River channel to +72 mV in the development site sediments in July 1975 (Table 27). Development site sediment Eh values continued to increase during the next 1.5 years, especially at the high marsh site where a mean of 274 ± 194 mV was observed in January 1977. Eh values at the reference marsh were also most positive in the high marsh zone (192 ± 236 mV). Redox potentials did not change appreciably with depth except

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* Depths for the lower sections of the cores collected in July 1975 were from 86 to 104 cm for two subtidal cores and 104 to 130 cm for two intertidal cores (Tables B'21 and B'22).

in the high marsh locations where the Eh values at 25 to 50 cm depth were decreased and similar to average values at the other coring sites.

29. Interstitial water chemical values in the sediments 6 months after dredged material disposal were compared with the calculated concentrations of various dissolved substances in the effluent water during active dredging. The calculations are mentioned in Part III of Volume I and are based on the assumption that effluent chemistry was influenced by the mixing of James River channel sediment interstitial water and James River overlying water (ignoring solids) in a ratio of 1 part interstitial water to 4 parts river water (Table 23 in Volume I). The dissolved orthophosphate-P concentration in the interstitial water of the development site sediments 6 months after dredging averaged 0.054 mg/ℓ, which was between the calculated orthophosphate concentration of 0.08 mg/ℓ in the effluent during dredging and the measured value of 0.030 mg/ℓ. Interstitial ammonium-N was more than twice as high (31 mg/ℓ) in July 1975 compared with the calculated value of 13 mg/ℓ. Changes in total nutrient concentrations as a result of dredging were about 25 percent: total phosphorus increased from 662 to 814 μg/g while total Kjeldahl nitrogen decreased from 4,577 to 3,376 μg/g (Table 28).

30. Dissolved orthophosphate-P composed about 50 percent of the total dissolved phosphorus (TDP) compounds in the development site and reference marsh interstitial water in January 1977 (average PO_4 = 0.06 mg/ℓ, TDP = 0.15 mg/ℓ) as it did in the channel sediments in January 1975 (average PO_4 = 0.25 mg/ℓ, TDP = 0.46 mg/ℓ). During the summer seasons this relationship decreased to between 24 and 33 percent (average PO_4 = 0.06 mg/ℓ, TDP = 0.20 mg/ℓ) with the exception of August 1976 at the development site where interstitial orthophosphate-P composed 70 percent of the total dissolved phosphorus in the sediments (average PO_4 = 0.10 mg/ℓ, TDP = 0.14 mg/ℓ). There were no appreciable seasonal changes in total dissolved phosphorus at either marsh: orthophosphate-P decreased slightly at the development site and increased from 0.06 to 0.08 mg/ℓ at the reference marsh between August 1976 and January 1977 (Table 28). Total dissolved phosphorus concentrations increased with depth in the sediment of the intertidal and subtidal zones of the development site

and subtidal zone of the reference marsh in August 1976; in January 1977 total dissolved phosphorus increased with the depth in the high and intertidal reference marsh zones.

31. Dissolved ammonium concentrations in the James River channel sediment interstitial water was 63 mg/ℓ, about 90 percent of the total dissolved nitrogen concentration (Table 28). This proportion remained nearly constant for the development site sediments 6 months after dredging even though the overall concentrations of both parameters decreased by about half. Between July 1975 and August 1976 a dramatic decrease occurred in the ratio of dissolved ammonium to total dissolved nitrogen (TDN) concentration (from 90 percent, as above, to 21 percent) as well as in the average concentrations of each parameter (Table 28). During the growing season at both marshes, the dissolved ammonium concentration was only 16 to 20 percent of the total dissolved nitrogen. This increased in the winter to 50 to 53 percent. The concentrations of both ammonium and total dissolved nitrogen were lower in the interstitial waters at the reference marsh than at the development site (Table 28). With the exception of the subtidal site at the reference marsh in August 1976, there was an increase in total dissolved nitrogen with depth at all locations regardless of the season. The same was true for dissolved ammonium with the exception of the high reference marsh zone in August 1976 and the intertidal and subtidal reference marsh zones in January 1977. Even though they were a few metres apart, cores from the intertidal and subtidal zones of the reference marsh in January were collected closer to an area that had supported denser vegetation during the previous growing season than was the case for August cores, which were collected in the middle of the small channels.

32. The interstitial concentration of dissolved nitrate plus nitrite in the sediments of the development site increased in time for an average of 0.02 to 0.11 mg/ℓ (Table 28). The seasonal changes in nitrate and nitrite were negligible at both the development site and reference marsh. During the summer, dissolved nitrate and nitrite decreased with depth in the cores at both marshes except at the high reference marsh zone where it increased. The high reference marsh zone

was also the only location at either marsh where ammonium decreased with depth during the summer and was the location with the most abundant plant growth. Depth distributions in the winter were not consistent with those of the summer. Interstitial nitrate and nitrite increased with depth at the high reference marsh zone but concentrations with depth at the other sites were almost constant.

33. Dissolved organic carbon (DOC) values at the development site were high and averaged 61 mg/ℓ in July 1975, 6 months after dredging. A comparison could not be made with the channel sediments because of the lack of data. Dissolved organic carbon decreased to 36 mg/ℓ at the development site in August 1976 (Table 28), or a change of 40 percent. January concentrations of dissolved organic carbon were only half the level of the August measurements at both the development site and the reference marsh. The overall concentrations at the reference marsh were 20 percent less than those at the development site; however, because of the variation in the data this difference was probably not significant. All of the development site zones had middepth dissolved organic carbon maxima in August, while this was the case for only the subtidal location in January. Dissolved organic carbon concentrations at the reference marsh in August 1976 decreased with depth in the high marsh and intertidal zones and increased in the subtidal zone. Depth concentration profiles in the sediments remained relatively unchanged the following January.

34. Total sediment phosphorous (TP), which averaged 662 μg/g in the James River channel, increased by 23 percent to an average concentration of 814 μg/g at the development site six months after dredging (Table 28). For the next 1.5 years,total phosphorus decreased to an average concentration of 746 μg/g during the first year and to 690 μg/g in the next six months (January 1977). Values at the reference marsh remained relatively constant between seasons and averaged 3 to 25 percent lower than at the development site. There were no consistent trends with depth in the cores during August, but in January total phosphorus concentrations usually decreased with depth in both marshes, except at the high reference marsh zone. Total Kjeldahl nitrogen, which averaged

4,577 μg/g (0.46 percent) in the channel sediments, decreased to an average concentration of 3,376 μg/g, or a 27 percent change, at the development site 6 months after dredging. Also at this time, total organic carbon measured 17,140 μg/g (1.7 percent) at the development site. Both parameters decreased substantially during the subsequent year. Total Kjeldahl nitrogen was depleted from 3,376 to 765 μg/g, while total organic carbon decreased from 1.7 to 1.0 percent (Table 28). There was a further decrease in total sediment nitrogen by about 30 percent between August and January at both the development site (from 765 to 531 μg/g) and reference marsh (from 1,540 to 1,010 μg/g). There was little difference in total organic carbon content of the sediments between the two marshes in August and January, yet total Kjeldahl nitrogen in the sediments of the reference marsh was about double the concentrations of the development site during the same time period.

35. Interstitial water metals chemistry. Sediment interstitial water calcium decreased from an average of 216 mg/ℓ in the James River channel cores to 61 mg/ℓ in the development site sediments 6 months after dredging. This value was only 13 percent above the predicted concentration of 54 mg/ℓ for mixing of channel porewater with James River water during dredging (Table 23 in Volume I). By August of 1976, dissolved calcium had reached an average level of 82 mg/ℓ, but then decreased 20 percent to 65 mg/ℓ in January 1977 (Table 29). Interstitial dissolved calcium at the reference marsh averaged 26 and 13 mg/ℓ in August 1976 and January 1977, respectively. Dissolved interstitial iron decreased from values of 57 mg/ℓ in the James River channel to 24 mg/ℓ at the development site in July 1975. This was about double the predicted concentrations during dredging (Table 23 in Volume I), which suggested solubilization of precipitated iron within the sediments of the development site shortly after filling and consolidation. In August 1976, dissolved interstitial iron concentrations averaged 31 mg/ℓ, an increase of 30 percent over the previous summer. This value decreased to 21 mg/ℓ in January 1977. Interstitial dissolved iron in the reference marsh sediments averaged 34 and 12 mg/ℓ in August 1976 and January 1977, respectively, or about a fourth of the channel sediment porewater concen-

trations during similar seasons (Table 29). Concentration trends of dissolved manganese were similar to those observed for interstitial calcium and iron. A decrease from 6.9 to 2.7 mg/ℓ, or 61 percent, occurred from the James River channel sediment values to those at the development site 6 months later. As with iron, this was about double the predicted concentrations,which again suggested solution of solid phases within the recently deposited dredged sediments. Manganese concentrations then increased by 42 percent to 3.8 mg/ℓ in August 1976, and decreased by 26 percent to 2.8 mg/ℓ in January 1977. Interstitial dissolved Mn averaged 1.4 mg/ℓ at the reference marsh in August 1976 and January 1977, or about a fifth of the mean channel sediment interstitial water concentration during the same season. Dissolved zinc increased from 0.12 mg/ℓ* in the channel sediment interstitial water to 0.32 mg/ℓ during July 1975 in the artificial marsh sediment porewater (Table 29). These concentrations for the development site interstitial waters in July 1975 were four to five times greater than predicted concentrations during dredging (Table 23 in Volume I), which indicated mobilization as had occurred during dredging. By August 1976 the interstitial water concentration of dissolved zinc at the development site averaged 0.06 mg/ℓ, a sizeable decrease from 0.32 mg/ℓ during the previous summer. These concentrations remained through January 1977. At the reference marsh, interstitial dissolved zinc was 0.08 and 0.05 mg/ℓ for August 1976 and January 1977, respectively. These levels were about half of the mean James River channel concentrations.

36. In summary, dissolved calcium, iron, and manganese exhibited similar interstitial water concentration patterns of large decreases (60 to 70 percent) following dredged material disposal into the development site; 30 to 40 percent increases from July 1975 to August 1976; and slightly lower decreases (20 to 30 percent) from August 1976 to January 1977. Zinc concentrations in the interstitial water increased during dredging, then decreased by approximately 80 percent from July 1975 to August 1976 to negligible concentrations and remained at these

* Three values greater than 1 part per million were rejected as not being representative.

levels from August 1976 to January 1977. At the reference marsh, dissolved interstitial calcium and manganese were lower than at the development site during both August 1976 and January 1977, while interstitial dissolved iron and zinc were approximately equal at the two marshes during the summer. The apparent decrease in interstitial dissolved calcium and iron from August to January seemed to be greater at the reference marsh than at the development site. Dissolved zinc at the development site and manganese and zinc at the reference marsh did not appear to change appreciably from August 1976 to January 1977.

37. Interstitial dissolved cadmium, nickel, and lead were detected only in the James River channel sediments and averaged 0.009 mg/ℓ, 0.054 mg/ℓ, and 0.077 mg/ℓ, respectively (Table 8 in Volume I). Analyses of interstitial water collected from the development site in July 1975 suggested that the mixing of the dredged material with James River water lowered concentrations of these three metals to below the detection limits. Dissolved copper concentrations averaged 0.010 mg/ℓ in the interstitial water of the channel sediments but were not analyzed at the development site in July 1975 due to insufficient sample volume. This metal was lower at the development site than at the reference marsh in August 1976 and was below detection at both marshes in January 1977. Dissolved chromium was not included in the analysis scheme until after July 1975 and was detected only in the August 1976 sediment porewater at both marshes (Table 29). Interstitial mercury from the channel sediment cores averaged 3.2 μg/ℓ. Data were not available for July 1975. In August 1976, interstitial mercury concentrations averaged 5.6 μg/ℓ at the development site and 4.0 μg/ℓ at the reference marsh. By January 1977, mercury levels had sharply decreased to 0.8 μg/ℓ at the development site and 0.6 μg/ℓ at the reference marsh. Thus, both dissolved copper and mercury were more abundant in August 1976 at both marshes than in the channel sediments, while winter conditions resulted in their depletion in the marsh sediment porewater.

38 . Total sediment metals chemistry. The descending order of total sediment concentrations in both marshes was as follows: Fe >> Ca >> Mn >> Zn >> Pb > Cr > Cu > Ni >> Cd > Hg. Iron had the highest

concentration of all metals measured for every time period, ranging from a minimum average of 3.4 percent dry weight in August 1976 at the development site to 4.1 percent in the channel sediment cores (Table 30). Total sediment metals concentrations were slightly higher in the channel sediments than in the development site in July 1975 except for nickel concentrations, which were nearly the same, and cadmium, which was slightly higher at the development site. Following dredged material disposal in the development site, total iron, calcium, zinc, lead, nickel, and cadmium decreased insignificantly from July 1975 to August 1976 followed by a minor increase in January 1977. No change was detected after July 1975 in total sediment manganese, calcium, and mercury at the development site. Chromium continued to decrease slightly after deposition in the development site. The total metals concentration in the reference marsh sediments were similar to those at the development site except for manganese, which was about one-third the average development site value. Contrary to the development site trend of a slight increase in iron, calcium, and zinc from August to January, these metals decreased slightly at the reference marsh (Table 30), but it should be noted that this could have been a result of a slight shift in coring stations from the subtidal reference marsh zone at midchannel in the summer to a location adjacent to the channel banks in the winter.

39. Mean total sediment calcium values were consistently about one-tenth those of iron in both marshes (Table 30). Total sediment manganese averaged 1100 μg/g in the channel cores, was 900 μg/g within the development site in July 1975, and remained relatively constant thereafter. Total zinc also decreased by 20 percent between the James River channel sediments to the sediments of the development site 6 months after dredging. There was little change thereafter (Table 30); but where manganese values were lower in the reference marsh, zinc was slightly higher and decreased by January 1977 to nearly the same concentration that was found in the development site during July 1975 (190 μg/g). Total sediment lead concentrations remained unchanged and nearly the same for both marshes. Total sediment chromium levels were essentially equal in the two marshes in August 1976 and January 1977.

During this interval (August to January), chromium decreased by one-third to 40 μg/g at both marshes, which, with the exception of total calcium at the reference marsh, represented the greatest change for any total metal concentration measured during both seasons. Total copper concentrations were essentially the same in both marshes with the highest mean value in August 1976 at the reference marsh (Table 30). Total nickel and cadmium did not show any pattern of change in concentration from the channel sediments to the development site and remained relatively constant throughout. Nickel concentrations at the reference marsh (40 μg/g) were 23 - 32 percent higher than at the development site (31 μg/g). At the reference marsh, cadmium concentrations were slightly lower for both the August 1976 and the January 1977 sampling periods as compared to the development site. Total sediment mercury had the lowest concentrations of any metal measured, averaging 0.2 to 0.5 μg/g for the entire sediment sampling program.

Geology of the marsh sediments

40. Comparison of the size parameters for the development site and reference marsh indicated the following:

- a The mean sediment size for all samples in the reference marsh (8.97 Φ or 2 μm) was significantly finer than the mean sediment size for the dredged material at the development site (7.56 Φ or 5 μm).
- b Sediments from both marshes were very poorly sorted.
- c Reference marsh sediments were slightly skewed towards the coarser sizes (-0.15 ± 0.05) while the development site sediments were slightly skewed towards the finer sizes (0.15 ± 0.14). This difference was statistically significant.
- d The 6 or 7 percent sand fraction was not significantly different between the two marshes.
- e The silt/clay ratio was significantly different between the reference marsh (0.55) and development site sediments (1.24).
- f The strongest mode at the reference marsh was also significantly finer (6.80 Φ or 9 μm) than the strongest mode of the sediments from the development site (5.34 Φ or 24 μm).

g The second strongest mode for the size distributions at either marsh was not significantly different (Table 31).

Similar sediment size distributions were collected from the James River channel, the development site, and the suspended material leaving the development site during dredging in January 1975. The reference marsh and tidally suspended sediments at the development site in May 1975 (3.5 months after dredging) were finer, more coarsely skewed, and contained more clay than the above three sampling locations or periods (Table 31).

41. Generally, the same clay minerals identified in the reference marsh and development site were also found in the river channel except that the high exchange capacity clays, vermiculate and smectite, were absent in the development site two years after it was created (based on only two samples; Table 32). The river channel and reference marsh sediments had about the same general proportion of clay mineral types as Tertiary age sediments in nearby cliffs along the river. The heavy minerals in the sand fraction from the reference marsh and artificial marsh were also different in relative abundance but both contained the same varieties (Table 33). The largest differences were mostly in the abundance of magnetite, tourmaline, staurolite, epidote, hornblende, and opaques.

42. Total sediment cation exchange capacity was significantly different between the reference marsh and development site in both the 0- to 10-cm and 25- to 50-cm depth intervals. The reference marsh cation exchange capacity averaged about twice that of the development site, where the mean cation exchange capacity in the surface sediments was 32.9 meq/100 g (Table 34). This difference in cation exchange capacity between the two marshes could be predicted from the clay mineral abundance using average exchange capacity values for each mineral listed in Table 32. The exchange capacity in the surface 0- to 10-cm-sediments at the reference high marsh zone was consistently higher by about 38 meq/100 g than either the intertidal or subtidal zones. The corresponding high marsh location at the development site was consistently lower in cation exchange capacity than either the intertidal or subtidal zones by about 18 to 40 meq/100 g depending on the amount of sand

in the sample (Table 34). Seasonal changes in cation exchange capacity between August 1976 and January 1977 were negligible at both marshes. Because analytical techniques were different for exchange capacity measurements of the river channel sediments and marshes, direct comparisons were difficult. Special tests on selected development site samples indicated that the exchange capacity measured as CaEC on the less than 2-μm freeze-dried fraction was about the same as the cation exchange capacity for the river channel sediments analyzed by the same technique (Table 35 and Appendix B'). Between July 1975 and June 1977, the change in cation exchange capacity was monitored for selected samples from the development site (Table 36). Although no significant change in exchange capacity occurred, the values measured in July and August 1976 were consistently higher than the earlier or later measurements.

43. The horizontal distribution of cation exchange capacity in the surface sediments of the development site during July 1976 indicated that the sediment closest to the tidal channels within the containment area were significantly lower as compared to sediment at the higher elevations (Figure 8). The average exchange capacity near the channels was 36.6 meq/100 g, while a mean of 43.0 meq/100 g was observed for the rest of the development site. The mean size, percent clay or volatile solids for the sediments were not significantly different between these two areas at the development site.

44. Organic matter and iron coatings contributed about twice as much to the total cation exchange capacity in January 1977 than in previous periods (Table 37). But January 1977 sediments were analyzed three to four months sooner than were collections from the earlier sampling periods. There was no significant difference in exchange capacity between the less than 62-μm fraction and the total sediment sample, as shown in Table 35. Organic matter exhibited a greater contribution to the exchange capacity than iron coatings, and the exchange capacity of sediments from both marshes in January 1977 were reduced by about 60 percent with the removal of organic matter.

45. Although the mean cation exchange capacity was approximately 32 meq/100 g at the development site and 60 meq/100 g at the reference

marsh (Table 34), the effective cation exchange capacity, as determined by base exchange for the nine metals measured during this program, was only about 7.1 meq/100 g at the development site and 9.4 meq/100 g at the reference marsh (Tables 38 and 39). In addition, sediments from intertidal and subtidal zones at the development site were analyzed for exchangeable magnesium, ammonium, potassium, and sodium, which averaged 1.9, 0.5, 0.13, and 0.6 meq/100 g, respectively. The mean sum of the exchangeable cations was about 10 meq/100 g, or about 25 percent of the total cation exchange capacity. Of other important cations known to occupy exchange sites, only aluminum and hydrogen were not measured.

46. The shear strength of the reference marsh sediments in August 1976 was consistently 37 percent higher than at the development site at all depths in July 1975 (Table 40). Shear strengths increased from summer to winter by approximately 46 percent at the development site and 39 percent at the reference marsh. Winter values at the reference marsh were only 26 percent higher than at the development site. As expected, there was a strong negative correlation (-0.82) between vane shear strength and water content at the reference marsh, but the correlation at the development site was only -0.58 (Table 40).

Discussion

47. The lower concentrations of dissolved nutrients and metals in the sediment interstitial waters from the development site collected 6 months after dredging, as compared to the James River channel sediment interstitial concentrations, were probably due primarily to dilution with James River water during dredging. Dissolved iron and orthophosphate-P concentrations were possibly reduced because of coprecipitation resulting from more oxidized conditions during dredging and disposal. Assuming that the interstitial water at the development site was the entrapped effluent water during dredging, then the slight increase in dissolved iron and manganese during the intervening 6-month period could be accounted for by dissolution of less than one percent of the total sediment metals or even less than one percent of the metals absorbed on the sediment

surfaces with the exception of iron. Some increase in dissolved iron concentration, and possibly manganese concentration, may have come from the easily reducible phases (predominantly as manganese oxides and hydroxides) or dissolution of iron oxides because of changes in redox potential and possibly pH in the development site sediments compared to conditions during the dredging period. The decrease in both sediment pH and Eh therefore may have accounted for the slight increase in the interstitial metals concentrations in July 1975, 6 months after dredging. Because the redox potential at the development site was never as low as the values measured in the river channel sediments, dissolved metals and nutrients at the development site remained below their former concentrations in the channel.

48. Regardless of any changes in the dissolved components from the James River channel sediments to those at the development site, the total metal concentrations remained relatively unchanged during dredging except for possible slight decreases in calcium, manganese, and zinc. Total sediment nitrogen content also decreased slightly while phosphorus increased. Minor changes were due to the higher total sediment concentrations relative to the dissolved components. If all dissolved metals had precipitated during or shortly after dredging, the total sediment concentrations would not have increased significantly (Table 41). Although volatile solids decreased dramatically from the channel sediments (14.5 percent) to the development site (4.9 percent), total metals concentrations were not significantly affected because apparently no more than 12 percent were associated with the organic phase (Table 38). Most of the loss in volatile solids from the sediment was probably due to the removal of plant debris by flotation, which was observed during dredging. Based on the percentage of metals in the organic phase of the sediments, only about half of the slight but insignificant loss in the concentrations of total sediment lead, copper, and zinc, and even less than half of any possible depletion, if it had occurred, in other total metals could have been accounted for by this decrease in volatile solids. The loss of volatile solids apparently had little effect on the exchange capacity of the channel and the development site sediments

despite the usually high contribution to exchange capacity by organic matter as noted for similar sediments (Schneitzer 1965 and Rashid 1969). Either the loss in volatile solids was due to mostly large, but low exchange capacity plant debris, or the channel sediment cation exchange capacity was due mainly to inorganic species rather than organic matter. This problem was not resolved because of analytical problems associated with the determination of organic cation exchange capacity by H_2O_2 treatment, as discussed in Part III of Volume I.

49. Even though dredging resulted in the dilution of interstitial chemical components with overlying river water, this mixing process resulted in only a few noticeable significant differences between interstitial chemical concentrations at the development site and a nearby reference marsh. Only calcium and manganese were different. Calcium concentrations were three times higher in the interstitial waters of the development site because more calcium was probably absorbed onto exchange sites at the reference marsh where the sediment cation exchange capacity was twice that measured at the development site. Calcium was the most abundant cation associated with the exchangeable phase of the sediments. It also behaved conservatively during the dredging and settlement period, where the predicted concentration of 54 mg/ℓ was only 13 to 17 percent less than the measured value at the effluent pipe during dredging (63 mg/ℓ) and in the interstitial water 6 months later (61 mg/ℓ). Interstitial dissolved manganese concentrations were about twice as high at the development site because the total sediment concentrations were about three times higher than at the reference marsh.

50. There were several other differences between the development site and the reference marsh, such as total Kjeldahl nitrogen, cation exchange capacity, sediment size, percent water, percent volatile solids, percentages of various heavy minerals, clay mineral content, redox potential, and pH. Because the total sediment and interstitial water concentrations at the two marshes were similar for many of the other metals and nutrients, the sediment cation exchange capacity was probably one of the most important factors in determining the concentration of dissolved calcium, the most abundant interstitial cation.

Also, variations in sediment size, minerology, volatile solids, Eh, and pH were probably not important enough to cause statistically significant differences between the two marshes with respect to most of the total or interstitial water chemical parameters. Apparently the sediments and water at both marshes had common sources and the differences between the two marshes were mainly a result of the depositional process that formed them as well as differences in physical setting and age. Obviously, the reference marsh was not formed by rapid deposition of homogenized sediments from a short section of the river channel and was not surrounded by sand dikes like the development site. Because they were most likely deposition from tidal currents and not a dredged slurry, the reference marsh sediments were finer grained and contained slightly different mineral abundances as compared to the development site. This concept was supported by the similarity in sediment size distribution at the reference marsh and the tidally suspended material at the development site (Table 31). The depositional processes in the river channel, which had the same sediment size distribution as at the development site, were most likely different than those at the reference marsh where tidal currents were much slower. Therefore, the similarity of heavy minerals at the two marshes suggested a common source of sediments, while differences in heavy mineral percentages were due mainly to the location of the reference marsh, and its slower currents, relative to the river channel from which the development site sediments were obtained. Besides the difference in sediment size distributions at the two marshes, slight differences in clay mineralogy and initial low volatile solids content at the development site were probably due to the different depositional processes that formed each marsh. Because of their small size and disc shape, smectite and vermiculite (two minerals with high cation exchange capacity values) were apparently floated out of the development site during or shortly after dredging along with most of the plant debris and other organic matter.

51. The older age of the reference marsh could possibly account for its lower total manganese and pH and higher total Kjeldahl nitrogen, volatile solids, and sediment shear strength values. Solid manganese

apparently was slowly solubilized below the marsh surface, with the result that dissolved manganese migrated upwards and was eventually lost to the overlying tidal waters. As shown in Part III of this volume, dissolved manganese was exported and particulate manganese imported at both marshes during August and January. The rate of net export was 17 times higher in the summer at the reference marsh as compared to the winter, while there was a difference of four at the development site. This suggested that bioturbation rather than diffusion was the dominant mechanism for transfer of manganese from the sediments. Concentrations of several total sediment metals (cadmium, calcium, copper, lead, and zinc) suggested a depletion with depth in the reference marsh sediments, which was not always the case for the development site (Table 42). If it is assumed that both marshes had similar sources as indicated above, and thus the same original total metal concentration, approximately two-thirds of the total manganese at the reference marsh was lost by such dissolution processes. This, however, did not seem to be the case for the other total metals. Higher volatile solids and total Kjeldahl nitrogen at the reference marsh were probably due to the accumulation and decomposition of plant debris and other types of organic matter over a long period of time. Such processes are known to lower pH and increase the total nitrogen content of the sediments (Black 1968 and Bolt and Bruggenwert 1976). This created an environment with a mean pH about 0.5 units lower than at the development site, which certainly aided in the solubilization of manganese. The pH may have been buffered by the sediment cation exchange capacity, where up to 75 percent of the exchange capacity could have been occupied by hydrogen ions as was suspected for estuarine sediments in the nearby Rappahanock River (Nelson 1962). This buffering or selective H^+ adsorption may effectively prevent the depression of pH in freshwater marshes as well as estuarine sediments. Bolt and Bruggenwert (1976) noted that hydrogen ions have a highly selective association with organic ligands and oxide surfaces and that addition of a neutral electrolyte was needed to decrease pH. The downward percolation of rain water, a nearly neutral electrolyte, through the high marsh zone of the development site probably resulted in a greater lowering of pH with time. At least this was more important than the oxidation of iron, which occurred to a greater extent in the high marsh zone and would increase pH levels (Singer 1977).

52. Well-developed root systems, which were especially noticeable in the high marsh zone of the reference marsh, accounted for some of the greater sediment shear strength at the reference marsh. Slow compaction over more than 200 years would also be an important factor. If greater compaction along were the cause of higher shear strength, the reference marsh should have lower instead of higher water content than that at the development site. Because total manganese (and thus dissolved manganese), volatile solids, pH, total Kjeldahl nitrogen, and shear strength differed between the two marshes as a result of age differences, in the future these parameters at the artificial marsh should approach values measured at the reference marsh.

53. Another difference between the development site and reference marsh, which may have been due to their modes of formation and physical setting, was the variability among sampling sites. Excluding the sandy high marsh area at the development site, there was less of a difference between the other two development site locations than existed between sampling sites at the reference marsh. This was especially noticeable for redox potential, total Kjeldahl nitrogen, dissolved nitrate and nitrite, dissolved total nitrogen, dissolved ammonium, total sediment phosphorus, volatile solids, cation exchange capacity, and sediment particle size, which varied more between sites at the reference marsh than between the intertidal and subtidal locations at the development site (Appendix C'). The greatest variation at the reference marsh occurred between the high marsh zone and the other two locations. Also, there was a greater variation between the intertidal and subtidal zones at the reference marsh as compared to similar locations at the devleopment site. Obviously, the close resemblance in physical setting for the subtidal and intertidal coring locations at the development site was responsible for the similarity in nearly all measured parameters at these locations. The intertidal zone at the

reference marsh contained much more plant growth as compared to the subtidal zone. This location could have been part of an old dike built during colonial times, which would also explain this site's greater vane shear strength. Although the high marsh sites at both marshes contained the most sand, because of the nearby dikes, the high marsh at the development site had more than twice the sand that existed in the high zone of the reference marsh. This location at the reference marsh also contained the greater density of marsh plants compared with the other two locations. The subtidal reference zone was located in the middle of an unvegetated tidal channel in the summer. The winter subtidal reference sampling location was situated near tidal channel banks adjacent to an area of relatively dense plant growth and within about 2 to 3 m of the previous summer's location. Thus, much of the variability among sampling locations at the reference marsh was due to the choice of different physical settings.

54. Because variations among replicates were large (Tables 28 to 30) for most parameters, only very large differences at the development site from July 1975 to August 1976 were probably statistically significant. Total dissolved phosphorous and nitrogen, dissolved ammonium, dissolved organic carbon, total Kjeldahl nitrogen, total sediment phosphorus, and total organic carbon all decreased sharply at the development site, possibly as a result of increased plant growth during the second summer and higher rates of aerobic microbial activity as compared to the anaerobic conditions in the channel. The change in total sediment phosphorus was not as noticeable as with the other parameters, probably because of precipitation of dissolved phosphate with ferric iron in the surface sediments. This would not be the case for the end-products of organic nitrogen and carbon decomposition, which could eventually be lost to the atmosphere (as N_2O, N_2, or CO_2) or to the overlying tidal waters. Only dissolved orthophosphate-P and nitrates plus nitrites increased during the period from July 1975 to August 1976. Bacterial nitrification under oxidizing redox conditions in the sediment surface zone and burrow holes of organisms certainly aided in creating the higher levels of dissolved nitrates and nitrites.

Perhaps aerobic bacterial decomposition of some of the abundant dissolved phosphorus compounds (0.22 mg/ℓ) in July 1975 to about half this concentration by August 1976 released a greater amount of interstitial dissolved phosphate than would normally be present during the growing season. The lack of vertical gradients with depth in the sediments at either marsh for total dissolved phosphorus and dissolved orthophosphate-P suggested that plant utilization and perhaps burrowing organisms aided in homogenizing these sediments within the upper 50 cm. The lack of distinct sediment laminations also supported physical mixing. Total nitrogen, on the other hand, decomposed to dissolved organic and inorganic compounds faster than these components were utilized by plants or lost to the overlying waters by mixing and diffusion processes, therefore increased concentrations with depth in the sediments were observed. Dissolved ammonium increased with depth at all locations except at the high and intertidal reference marsh zones where vegetation was denser in the summer. Plant roots may have utilized and depleted dissolved ammonium down to the 50-cm depth at these two sites. The difference between the depletion of dissolved ammonium and orthophosphate-P in the surface 50 cm was probably enhanced by the greater solution mobility of the former and the higher absorptivity of phosphate onto sediments (Black 1968) as well as precipitation of orthophosphate with oxidized forms of iron in sediment borrows created by organisms and spaces around plant roots.

55. The difference in total Kjeldahl nitrogen between the channel sediments and the development site suggested that these organic materials were easily decomposable and that the nitrogen components were rapidly mineralized under such subaerial conditions. Because higher rates of nitrogen as compared to carbon decomposition were reported for organic detritus in lake water (Koyama and Tomino 1967) and opposite results were reported for leaf mineralization in hard water systems (Wetzel and Manny 1972), decomposition of organic matter at the development site apparently depended on the type of material as well as the bacterial population. Nitrification in the surface 0 to 10 cm could lead to a significant loss of soil nitrogen (Keeney 1972 and Serruya

et al. 1975), while denitrification in the waterlogged, oxygen deficient sediments below the surface could result in further losses through N_2O and N_2 protection. The soluble products of total Kjeldahl nitrogen mineralization (i.e., total dissolved nitrogen and ammonium) would accumulate in the deeper sediments. These components would be mixed into the surface through bioturbation and methane degrassing where oxidation and/or subsequent losses to the overlying tidal waters would occur. High mineralization rates of total Kjeldahl nitrogen were substantiated by the increased concentrations of total dissolved nitrogen and ammonium with depth in the sediments at all of the development site zones during both seasons (Appendix C') and the sizeable net mass export of total dissolved nitrogen compounds (8.7 kg/tidal cycle) during August 1976 (Part III of this volume). This was not the case for orthophosphate-P and dissolved total phosphorus. The continual loss of sediment Kjeldahl nitrogen as dissolved components at the development site (Table 43) could eventually produce a nitrogen deficient system requiring substantial nitrogen subsidy, such as bacterial nitrogen fixation, for future plant growth (Brooks et al. 1971).

56. With the exception of total Kjeldahl nitrogen, nutrient depletion due to diffusion, bioturbation, or plant utilization, balanced by enrichment from the decomposition of total nutrients, seemed to attain equilibrium conditions at the development site within two years (Table 28). By August 1976, dissolved and total nutrients at the development site were nearly the same as those at the reference marsh. Only total Kjeldahl nitrogen remained at a significantly lower level at the development site; this condition occurred very rapidly during the first one and one-half years after dredging and disposal operations. This assumed, of course, that the reference marsh was at or near equilibrium with respect to the balance between plant productivity and the bacterial regeneration of nutrients and that the concentrations of total sediment and interstitual water components would reflect such relationships. Because of its age the reference marsh should probably be close to equilibrium, although this investigation did not represent a long enough period of data collection to confirm such a hypothesis. Recent changes such as nearby dredging activities, applications of pesticides and fertilizers on adjacent fields,

and the unusual introduction of Kepone just upstream of this site could have altered the natural processes toward equilibrium, yet there were no data to confirm or reject this possibility.

57. The slightly higher concentrations of sediment interstitial calcium, iron, and manganese at the development site from July 1975 to August 1976 were probably due to the mobilization of these ions from the easily reducible phase, especially in the intertidal and subtidal development site zones where greater plant growth and tidal mixing may have depleted near surface (0 to 10 cm) concentrations. It is suspected that the precipitates of iron and manganese that were formed during dredging due to the rapid changes in redox conditions were relatively unstable and could be solubilized once deposition and consolidation of the sediments within the diked containment area occurred. Conditions would then be more favorable (i.e., a lowering of redox and perhaps pH) for their solubilization. Even though there was an increase in sediment concentrations of dissolved calcium, the mechanisms were not clear since the budget calculations (Table 23 in Volume I) did not suggest precipitation of calcium during dredging. These subtle changes during this 13-month interval were probably not statistically significant due to the large variability in the data (Table 29). Monitoring of the two marshes during a longer time period would provide a better understanding concerning trends in dissolved calcium, manganese, and iron at the development site. Interstitial zinc concentrations decreased significantly from July 1975 to August 1976 at the development site (Table 29). Even though Lee et al. (1976) did not report a substantial uptake of zinc by two freshwater marsh plants, nevertheless studies at the development site suggested that the reduction in zinc at this marsh was related to plant growth, because most of the decrease in zinc concentration occurred in the intertidal and subtidal development site zones where abundant vegetation was evident. Sample contamination as evidenced by the high variability in the measurements of zinc was also a possibility (Subramanian et al. 1978) since sample containers were not cleaned according to the method outlined in Moody and Lindstrom (1977). This would account for some of the variability in the data but not for the depletion in inter-

stitial zinc concentrations at the development site during the 13-month interval. Significant changes were not evident with respect to the total metals during this time interval, but for this to have occurred abnormally high rates of weathering would have been required.

58. Although the surface sediment cation exchange capacity near the tidal channels at the southeast corner of the development site were approximately 7 meq/100 g lower than values for the rest of the development site during July 1976, other parameters were not significantly different between these two areas. If this change had occurred since the time of original deposition, resuspension and removal of finer, high exchange capacity clay minerals and colloids due to tidal action within and adjacent to the channels near the two entrances to the development site could have explained such losses. Because a survey of cation exchange capacity over the entire marsh prior to July 1976 had not been conducted, it is suggested that the lower surface values were due to the winnowing of these minerals and colloids during initial deposition.

59. The average 24° C drop in mean temperature from summer to winter may have caused a decrease in the concentration of dissolved metals in the sediments at both marshes (Table 29) because of the lowering of solubility with decreasing temperature. This was reported (Florence 1977) for the labile forms (measured as ionic species by anodic stripping voltometry) of copper and lead in natural water samples. Such would not have been the case for dissolved calcium, which should have increased when the temperature was depressed. The lowering of temperature may also have caused a decrease in interstitial dissolved organic carbon (Table 28) by promoting polmerization and precipitation of organic compounds in the winter (Akiyama 1973). Freezing has been used as a method for concentrating organic matter dissolved in water samples (Baker 1967), and therefore could have coprecipitated chelated and complexed metals. Even though Katsaounis (1977) found no correlation between interstitial dissolved organic carbon and dissolved mercury at the two marshes, this process was probably more important for the major dissolved metals than changes in solubility product constants because a greater decrease in dissolved metals was indicated at the

high marsh zones at both marshes where most of the depletion in interstitial dissolved organic carbon also occurred (Appendix C').

60. The overall increase in levels of dissolved ammonium in the sediments during the winter at both marshes was probably due to a lack of plant utilization during the winter as well as higher nitrification within the sediments during the summer as a result of higher evaporation demand leading to more oxygen diffusion into the sediments, higher levels of bacterial activity, and increased mixing of the sediments by organisms (bioturbation). Dissolved ammonium decreased in the sediments at the subtidal coring location at the reference marsh between August 1976 and January 1977; this was probably due to the change in sampling from mid-channel in the summer to a location adjacent to the bank of the channel in the winter. Thus, winter cores from the subtidal zone of the reference marsh were collected from marsh sediments depleted in pore water ammonium by plant uptake during the previous summer. The pore water ammonium:total dissolved nitrogen ratio also changed from 1:4 to 1:6 during the summer to 1:2 in the winter primarily as a result of a larger net export of total dissolved nitrogen from the subtidal and intertidal zones of both marshes. As shown in Part III of this volume, this was the case for total dissolved nitrogen during the summer at the development site and during the winter at the reference marsh; if these net transport values are indicative of the yearly warm and cold climatic conditions, the overall transport of dissolved nitrogen compounds at both marshes would be a net export of about 6 kg/tidal cycle at the development site and 11 kg/tidal cycle at the reference marsh (similar calculations for dissolved ammonium were much lower, or net exports of 0.1 and 1.5 kg/tidal cycle, respectively). This was not the case at the high marsh sites where there were no significant differences in total dissolved nitrogen between the two seasons. The pore water of the two high marsh locations were both relatively low in total dissolved nitrogen compounds during the summer, but probably for different reasons. Rain percolation and dilution probably caused low values in the sandy sediments of the high marsh zone at the development site, while plant utilization or substantial aerobic decomposition resulted in low

total dissolved nitrogen concentrations, which decreased toward the surface, in the high marsh zone at the reference site.

61. The slight decrease in interstitial concentrations of orthophosphate-P from summer to winter at the development site may have been due to higher than normal August 1976 values (normal being defined by the reference marsh values). Winter values at both marshes were about the same, but summer values of total sediment phosphorus were somewhat higher at the development site. Aerobic decomposition and solubilization of some of the total sediment phosphorus could have caused higher levels of interstitial orthophosphate at the development site in August.

62. Except for total dissolved phosphorus and orthophosphate-P, total organic carbon, and possibly dissolved zinc, all chemical parameters had similar changes from summer to winter at both marshes. Pore water total dissolved phosphorus and orthophosphate-P as well as total organic carbon were similar at both marshes by January 1977. There may be a more uniform change in the future if the different seasonal changes, which were measured during the 1976-77 sampling period, were primarily due to the unusual August 1976 concentrations. Thus, although most nutrient levels were high at the development site in July 1975, or shortly after dredging, these levels decreased by January 1977 and approached concentrations observed at the reference marsh. Only sediment total Kjeldahl nitrogen remained significantly different after two years at the development site, where values were about half those at the reference marsh. Most of this difference in the mean total Kjeldahl nitrogen concentrations were due to the extremely low values in samples collected from the high marsh zone (215 μg/g) of the development site in January 1977. These low values could have been due to subsurface oxidative decomposition of nitrogen under consistently higher redox levels and the loss of ammonium and total dissolved nitrogen by dilution with percolating rain water or river water during higher than normal tides.

63. The only total sediment metal concentration that was significantly different from summer to winter was chromium, which decreased from 63 to 40 μg/g at both marshes (Table 30). The cause for this

change has not been resolved, but sediments at all depths at the high marsh locations at both marshes were reduced in total chromium concentrations relative to lower marsh sampling locations (Appendix C').

PART III: CHEMICAL FLUX CHARACTERISTICS OF A DREDGED MATERIAL MARSH AND A NATURAL MARSH

Introduction

Purpose

64. In order to assess the mobilization of contaminants at the artificial habitat, the tidal entrances to this marsh (Figure 3 in Volume I) and a natural reference marsh located 3.5-km upstream (Figures 1 and 2 in Volume I) were monitored during one summer and one winter over a 48- to 52-hour interval. This assessment involved the calculation of mass fluxes from concentration and volume data so that net gains or losses at the dredged material and natural marshes could be determined and compared.

65. Approximately 40,000 m^3 of tidal water usually entered the development site through two 0.91-m diameter pipes and a natural breach with a maximum cross-sectional area of 2.16 m^2 in August 1976 and 3.12 m^2 in January 1977 (Figure 9). During low tide the breach was dry while tidal water continued to flow through the pipes. In fact, water continued to drain from within the dike during the last portion of the ebb tide when the water level was below the elevation of nearly all of the sediment surface. This phase of the sampling period was termed pore-water drainage (PWD). When the ebb flow at the breach ceased, current velocities at the pipe increased (Figure 10). Sediments around the breach were composed primarily of sand derived from the dike while fine sand to clay dominated the exterior and interior channels leading to the pipes. In fact, in August 1976, dry sand was lifted by the flooding tide and rafted into the interior of the dike at the breach as part of a surface film. While sand from the dike formed a thin deposit over the dredged muds and extended 30 m inside the development site at the breach, a large delta of fine-grained sediments was formed outside of the development site at the pipes. These fine sediments were partially resuspended by the flood currents, which, because of winnowing, resulted in a less than 3-cm thick layer of very fine sand over the delta.

66. Tidal currents at the development site (50 to 60 cm/sec) were frequently 5 to 7 times greater than those measured at the large channel of the reference marsh (8 to 10 cm/sec). Using an average tidal period of 12.42 hours, tidal height of 0.71 m (Table 1 in Volume I), and tidal volumes of 30,000 m^3 at the development site and 220,000 m^3 at the reference marsh, average current velocities calculated from cross-sectional areas given in Figures 9 and 11 (including 1.31 m^2 for the two pipes) were 50 cm/sec for the development site and 10 cm/sec at the reference marsh channels. These agreed closely with field measurements.

67. The majority of the tidal water passed through the two tidal channels (Figure 11) even though a third shallow channel was 250 m north of the large channel (Figure 2 in Volume I). Approximately one-third of the tidal volume passed through the small channel, which had a cross-section of 25 m^2 at a tidal height of 1.2 m as compared to a 45-m^2 cross-sectional area at the large channel.

68. There was no rain in August, yet overcast conditions occurred on the last day (Table 44). The greatest tidal range was 0.90 m during the entire sampling period. The weather conditions were somewhat anomalous in January 1977 as compared to other years. Temperatures were unusually cold (Table 45), and in fact the James River was frozen completely across near Ducking Stool Point a few days after the sampling program. A frontal system with snow moved into the area after the first 24 hours, and a rain squall along with increased wind velocities occurred near the end of the 54-hour sampling period. This was noticed as a slight warming on January 10 (see air temperature in Table 45). This last rain squall was termed preprecipitational ebb (PPE) because it resulted in a premature export of water from the marshes before the normal ebb flow. The greatest tidal range during the January 1977 sampling interval was 1.00 m. This unusually high tide was 0.61 m above those predicted in the tidal tables and 0.15 m above the previous high tide. This caused the larger tidal volume during January (238,000 m^3) at the reference marsh as compared to August (206,000 m^3), an increase in tidal volume of about 15 percent. The reason for the larger changes in tidal volume between sampling periods at the development

site was obscured by the fact that the overall tidal heights were different between August 1976 and January 1977 and that the cumulative area of tidal inundation changed between topographic surveys in 1976 and 1977 (Table 46). Substantial erosion had occurred at the lower tidal elevations during the 2-year period after construction of the development site. As an example, tidal water for a tidal height of 0.76 m occupied negligible surface area in the marsh in 1975, while the same tidal height inundated 1.2 ha of marsh in 1976 and 2.6 ha in 1977. Yet, the total area of inundation remained the same, or about 4.1 ha, during the entire period for tidal heights exceeding 1.37 m.

Methods and Materials

Field techniques

69. Field studies during the initial 1.5 years of the program consisted of collections every 6 hr at the effluent pipe during several 48-hour sampling periods (Volume I). The program during August 1976 and January 1977 was more intensive and consisted of hourly collections at both the development site pipe (AP) and breach (AB) during four complete tidal cycles. Station AP was located on the marsh side of the development site pipe, while samples at AB were collected from the center of the breach. In many instances, duplicate (alpha and beta) were collected simultaneously at each of the four locations in order to determine variability. At the same time, a similar study was conducted at the large (RL) and small (RS) channels of the reference marsh. A 5.8-m research vessel was anchored in the center of the large channel (RL) at the reference marsh, where a small boat was dispatched hourly to collect water samples at the small channel (RS).

70. The sample collection times, along with field current velocity measurements and WES tide gauge tidal height, during the August period are provided in Figures 12, 13, and 14, while similar information for the January period is shown in Figures 15, 16, and 17. Because current velocity measurements and water sampling were not always at the same times, each station, with the exception of RS where no velocity measure-

ments were made, is depicted separately. Water samples were processed for conductivity, temperature, pH, alkalinity, turbidity, total suspended solids, dissolved oxygen, dissolved and particulate nutrients (nitrogen and phosphorus), dissolved and particulate organic carbon, and dissolved and particulate metals (Ca, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn). In addition, chlorophyll and phaeophytin measurements, as well as the Fo/Fa ratio (fluorescence before (Fo) and after (Fa) acidification with HCl), were made. Current velocities were measured hourly at the development site pipe and breach using either an orange or water-filled balloon, while at the large channel of the reference marsh, a model 160 Endeco (Environmental Devices Corporation, Marion, Massachusetts) remote reading current meter was used for measurements collected at 15-minute intervals.

71. Many of the water and suspended sediment samples were composited before analysis to represent different stages of the tide.* Samples were occasionally collected for the determination of sediment cation exchange capacity (CEC), while more than half of the hourly total nutrient water samples were used to determine silt/clay ratios during different tidal periods. Measurements in the field were conducted for the following parameters: water and air temperature, dissolved oxygen, pH, alkalinity, and turbidity. Filtration for particulate nutrients, carbon, metals, and suspended solids, as well as for chlorophyll and phaeophytin determinations, were conducted at the field laboratory soon after collection. Filtered water samples for dissolved chemical components were stored at 1-2° C, while filters were frozen at -78° C. Ultrex acids were used for storage of water samples for dissolved metals. Dissolved oxygen was measured according to the micro-Winkler method described in Carpenter (1965). Standardized HCl was added to unfiltered water samples for alkalinity, whereupon the sample was bubbled for 15 minutes with nitrogen gas and back-titrated to pH 7.0 with standardized NaOH. Water turbidity was measured with a model 2100A Hach laboratory turbidimeter (Hach Chemical Company, Ames, Iowa).

72. Water samples for particulate and dissolved organic carbon were processed differently than samples for metals and nutrients, which were collected in acid-soaked polyethylene containers and filtered in

* This was done to reduce the number of analyses and yet obtain values representative of each tidal phase.

acid-rinsed plastic systems through membrane filters. The carbon samples were stored in preheated glass containers and filtered through tared pre-combusted glass fiber filters supported in stainless steel Sweeney filter holders fitted to 100-ml glass syringes. These water samples were frozen immediately at -78° C in pre-combusted scintillation vials with pre-combusted aluminum foil inserts. Filters used for particulate organic carbon analysis were stored between pre-combusted aluminum foil. Water samples were also passed through glass fiber filters for suspended solids and plant pigments (chlorophyll and phaeophytin); the latter were stored immediately at -78° C.

Laboratory methodology

73. The following parameters were either processed and measured in the field on an hourly basis or measured in the laboratory without compositing: water and air temperature, conductivity, pH, alkalinity, dissolved oxygen, turbidity, suspended solids, dissolved total organic carbon, dissolved volatile organic carbon, chlorophyll, phaeophytin, the Fo/Fa ratio, and dissolved calcium, iron, manganese, and zinc. These were termed serial data. Also, separate samples from stations AB and RS in August 1976 were not composited but analyzed individually for dissolved $NO_3 + NO_2$ and orthophosphate for comparisons with the composite data.

74. Water conductivity was measured with a model 8400 Autosal laboratory salinometer (Guildline Instrument, Larchmont, New York). Dissolved, volatile, and particulate organic carbon were determined with a model DC-52 Dohrmann carbon analyzer (Envirotech Corporation, Santa Clara, California). For plant pigments, the glass fiber filters were homogenized in 90 percent acetone with a Tekmar model SDT Super Dispax Tissumizer (Tekmar Company, Cincinnati, Ohio) and allowed to stand in the dark for 10 to 20 minutes. Fluorescence was measured on an Aminco fluoro-colorimeter (Aminco Bowman, Inc., Silver Springs, Maryland). Organic carbon samples (particulates on glass fiber filters and sediment TOC) were also homogenized with the Tekmar unit for measurement with the carbon analyzer.

75. Compositing of refrigerated water samples was completed within a few days after collection. Because of the restricted nature of the channels at the development site, tidal stages usually lagged behind the

normal rise and fall of water at the tide gauge and reference marsh. This was especially evident during ebb tide. Therefore, samples were composited according to field current velocity rather than tide gauge information (Tables 47 and 48). Slack water occurred at the same time as negligible current velocities at the reference marsh (Figures 14 and 17). Compositing according to tidal stage was performed for the following parameters: dissolved nutrients (inorganic orthophosphate, total dissolved phosphorus, ammonium, nitrate plus nitrite, and total dissolved nitrogen), total nitrogen and total phosphorus (from unfiltered samples), and dissolved mercury. For the August 1976 period, dissolved ammonium was measured by four different schemes to evaluate storage time and conditions: (a) immediately after compositing samples were stored at 4^{o} C with H_2SO_4 for seven days, (b) duplicate (alpha and beta) composite were stored frozen (-20^{o} C) for 42 days with perchloric acid, (c) single composites were stored frozen for 260 days (8.6 months) with H_2SO_4, and (d) duplicate (alpha and beta) serial samples were stored frozen for 225 to 240 days (7.5 to 8 months) with HCl. After thawing, this last set of samples were composited before analysis.

76. Particulate suspended material was collected by vacuum filtration through tared 0.4 to 0.6-μm Nucleopore membrane filters for metal analysis (Nucleopore Corporation, Pleasanton, California). These were leached with nitric acid and rinsed before the August 1976 sampling period. Later studies indicated that this precation was unnecessary and was therefore discontinued for the January 1977 period. Because of the low recovery of suspended material (approximately 1 mg per filter), all of the duplicates from similar tidal periods, i.e., low slack, flood, high slack, ebb, were combined into single tidal stages at each marsh. Enough material was collected during the flood tide at AP and RL in January 1977 to allow for the separate analysis of duplicate sets of composited filters.

77. Silt/clay ratios were determined for suspended sediments at both marshes in order to have an estimate of the colloidal clay fraction in transport. After thorough mixing, both the alpha and beta duplicate samples from the total nutrient water samples were used to obtain a 350-ml sample. Only those from hour 24 to 48 at station AP and from hour 16

to 48 at station RS were used. This provided at least one complete tidal cycle for both marshes. This sample was centrifuged at 750 rpm for 5 minutes in order to settle the >2 μm particles below a 19-cm depth in the bottles (Jackson 1973). From this depth, 200 ml of samples was pipetted into another centrifuge bottle. Enough saturated NaCl solution was added to both bottles to ensure flocculation. Bottles were than centrifuged at 2500 to 3000 rpm for at least 10 minutes. The supernatent was decanted and the sediment washed three times with methanol and deionized water to remove NaCl. The sediment was then dried at 60° C and weighed. The weight percent >2 μm, WP_2, was found by the following equation: $WP_2 = 100\ (a)(v)/200\ (a + b)$, where a is the dry weight of the >2 μm fraction pipetted from the sample, v is the original volume, usually 350 ml, and b is the dry weight of the remaining sediment containing all the >2 μm fraction. Thus, (a + b) is the total sample weight. Next, both of the size fractions were recombined and treated three times with 30 percent H_2O_2 in order to remove organic matter, then fully dispersed in deionized water instead of water collected from the James River. An increase in the silt/clay ratio with this latter step may have been due to incomplete disaggregation of the previously dried sediment.

Data evaluation techniques

78. A complete listing of measurements and other numerical observations are provided in Appendix B' for the two field programs at both marshes. Detailed statistics for each parameter are included in Tables C'61 to C'111 in Appendix C'. Data were divided into tidal stages according to the compositing scheme shown in Tables 47 and 48. Serial data were treated in the same manner. The pore water drainage period (PWD) at the development site pipe (AP) and the January 1977 preprecipitational ebb (PPE) samples collected at the development site breach (AB) and reference marsh channels (both RL and RS) were treated separately from the other tidal stages. Computer-generated data plots for each of the variables are provided in Appendix A'.

79. Topographic surveys were conducted three times at the development site in July 1975, April 1976, and March-April 1977 by NOA. One survey during August 1977 was completed at the reference marsh. From these surveys, 0.03-m contour maps of each marsh were constructed, and

surface area inundation for every 0.03 m of tidal height were made available by WES. Area inundation was first converted to tidal water volume. From the concentrations of each variable (serial or composite data), averaged field measurements of the current velocities, changes in water volume with tidal height, and cross-sectional changes at the development breach (Figure 9), tidal mass fluxes for each measured component during flood and ebb were calculated for the breach (AB). Mass fluxes for these parameters were then computed for paired floods and ebbs (usually four of each). Because the measurement of current velocity at the development site pipe was less accurate than of the breach, the calculation of mass flux, as detailed in Appendix D', was adjusted to allow the remainder of the tidal volume, i.e., that which did not flow through the breach, to enter or leave through the development site pipes (Table 49). Current velocity measurements at the large channel of the reference marsh (RL) were not used* because they indicated that only a third of the reference marsh tidal volume would have flowed through RL, which was very unlikely from a comparison of the cross sections for the two channels in Figure 11. Instead, the flux of tidal water entering or leaving through the two channels of the reference marsh was calculated according to changes in the ratios of their respective cross-sectional areas with tidal height (Table 50). As at the development site, mass fluxes were calculated for each ebb and flood and net mass fluxes were computed for the four complete tides.

80. An analysis of variance (ANOVA) was performed using a 2^6 factorial design (marsh, station, day/night, tide, replicate, block) for ebb and flood tidal groups only. Block refers to the first and second 24-hour periods. An F-test was used to determine if each term of the ANOVA was statistically significant. Only those terms significant at the five percent level or lower were considered. Measures of uncontrolled error were also determined by four different methods: (a) variations in the hourly serial data within a tidal group, (b) variations between replicates (alpha and beta), (c) variations between

* This discrepancy was due to the current meter which could not accurately measure the low velocities encountered.

time blocks 1 and 2, and (d) variations associated with the third and higher order interactions in the ANOVA. Further details and tables are provided in Appendix E'.

Results

Chemistry

81. During these two field programs, a total of 26 different parameters was investigated as to their tidal and seasonal variability as well as compositional differences between the sampling locations. Computer plots are shown in Appendix A', a data printout for each individual parameter is provided in Appendix B', while statistics related to tidal phases are in Appendix C'.

82. Ten parameters were higher at the tidal channels of both marshes during the summer as compared to the winter period. These were water temperature, turbidity, total Kjeldahl nitrogen, Fo/Fa ratio, chlorophyll, phaeophytin, dissolved calcium, dissolved manganese, dissolved mercury, and dissolved zinc (Table 51). Those parameters that were higher in the summer only at the development site were suspended solids, dissolved orthophosphate, dissolved total nitrogen, and dissolved iron. Conductivity was the only parameter that was exclusively higher in the summer than in the winter at the reference marsh. Yet, a seasonal difference was not well established for conductivity at the development site. There were only five measured parameters (pH, dissolved oxygen, oxygen saturation, dissolved NO_3+NO_2, and dissolved total phosphorus) that were higher at both marshes in the winter as compared to the summer. Of these, the largest differences were in dissolved oxygen and dissolved nitrate plus nitrite, with the latter having concentrations 2 to 3 times greater in the winter than during the summer. Dissolved total phosphorus and pH were also higher in the winter. The few parameters that indicated negligible seasonal changes at both marshes were dissolved ammonium, dissolved volatile organic carbon, and total dissolved organic carbon. Conductivity and total phosphorus did not seem to change between seasons at the development site while this was the case for suspended solids,

oxygen saturation, dissolved orthophosphate, and dissolved iron at the reference marsh (Table 51).

83. There were seven parameters, possibly 11, that were higher during both seasons at the channels of the development site as compared to the reference marsh. These were suspended solids, turbidity*, total phosphorus*, dissolved nitrate plus nitrite*, volatile dissolved organic carbon* (most noticeable at the development site pipe), dissolved calcium*, dissolved manganese*, and possibly conductivity*, dissolved total phosphorus, dissolved orthophosphate*, and dissolved zinc (Table 52). Dissolved oxygen* and pH* were the only two parameters that were higher during both seasons at the reference marsh as compared to the development site (see Table 53 for ebb and flood tide levels of significance). Dissolved total nitrogen, dissolved iron, and possibly TKN and dissolved total organic carbon were higher at the development site as compared to the reference marsh in the summer only, while in the winter this was the case for conductivity, alkalinity*, and phaeophytin* and possible water temperature and chlorophyll. Even though a significant difference existed for alkalinity between the two marshes in the winter (Table 53), the poor quality of the August data excluded ANOVA interpretation. Besides pH, dissolved oxygen, and oxygen saturation, which were higher at the reference marsh than the development site for both seasons, the Fo/Fa ratio was the one parameter that was higher only during the winter period. This was significant for the ebb and flood periods. Chlorophyll and phaeophytin were slightly higher (significant at least for the ebb and flood tides; Table 53) at the reference marsh for the summer only (Table 52).

84. A few of the measured parameters indicated some differences between the sampling stations at the tidal channels for each marsh. Suspended solids, turbidity, phaeophytin, dissolved total organic carbon, TKN, dissolved manganese, and possibly dissolved iron and dissolved orthophosphate were always higher at the development site pipe (AP) as

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* These parameters were significant during both seasons for at least the ebb and flood tidal periods, as shown in Table 53.

compared to the breach (AB), while this was possibly the case for TKN and total dissolved nitrogen at the large channel (RL) as compared to the small channel (RS) of the reference marsh for both seasons (Table 54). Only the Fo/Fa ratio might have been slightly higher at the breach during both seasons as compared to the pipes. Nine additional parameters, which were higher at the pipe as compared to the breach during the summer only, were conductivity, dissolved total phosphorus*, total phosphorus (unfiltered), dissolved volatile organic carbon, dissolved calcium*, and possibly dissolved mercury. At the breach, pH, dissolved oxygen (and oxygen saturation), dissolved nitrate plus nitrite, dissolved total nitrogen, chlorophyll, and possibly dissolved ammonium and dissolved zinc* were higher as compared to the pipe in the summer. Dissolved nitrate plus nitrite*, dissolved total nitrogen*, particulate carbon, and possibly chlorophyll and dissolved zinc* were higher at the pipe as compared to the breach during the winter sampling period, while conductivity, dissolved total phosphorus*, and total phosphorus* (unfiltered) were higher at the breach in winter. Data for particulate carbon were only available for the winter period, therefore, it was not known whether the summer would provide similar results. Dissolved total phosphorus*, total phosphorus (unfiltered), and dissolved nitrate plus nitrite were higher at RS as compared to RL at the reference marsh in the summer, while dissolved oxygen, chlorophyll, phaeophytin, and dissolved calcium* were lower (Tables 54 and 55). During the winter period, dissolved volatile and total organic carbon, particulate carbon, and dissolved iron were possibly higher at the small channel (RS) as compared to RL, while dissolved zinc*, and possibly dissolved total phosphorus*, dissolved ammonium, dissolved nitrate plus nitrite*, dissolved total nitrogen*, and TKN* were higher at RL as compared to RS.

85. The drainage of constituents from the development site pipes was also compared for the sum of three ebb tidal phases (PWD or porewater

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* These were significant at least for ebb and flood (Table 55).

drainage, ebb, and low slack) and the other periods of the tide (flood and high slack). Concentrations at the pipe were greater than at the breach because of the drainage of interstitial water from the interior sediments of the habitat. PWD and low slack tidal phases occurred only at the pipe because the breach was dry during this time period. As evidenced by eight different measured parameters (see those marked with an asterisk in Table 56), concentrations were higher for ebb tidal phases during both seasons of the year, while an additional six (suspended solids, turbidity, dissolved orthophosphate, dissolved total phosphorus, dissolved total organic carbon, and dissolved calcium) were higher only in the summer and TKN was the only parameter that was exclusively higher in the winter. Thus, 60 percent of the measured parameters at the habitat pipe during ebb were higher either for one or both seasons. None of the parameters were higher in the flood waters during both seasons; yet, during the summer, pH, dissolved oxygen (and oxygen saturation), dissolved nitrate plus nitrite, TKN, chlorophyll, and dissolved mercury were lower at the pipes during the ebb as compared to the flood (Table 56). Notably, the Fo/Fa ratio and dissolved zinc were the only parameters that did not show a tidal preference at the development site pipe during the summer, while the number increased to at least 16, and possibly 20, parameters in the winter (Table 56).

86. There were significant differences between the two marshes when the measured parameters were examined by ANOVA for the ebb and flood tidal periods only. At least 13 of the parameters were significant for both seasons (Table 53). Eight of these 13 parameters had higher concentrations at the development site: conductivity, total phosphorus, turbidity, and the dissolved components of phosphate, nitrate and nitrite, calcium, manganese, and volatile organic carbon. Dissolved iron, suspended solids, and total dissolved nitrogen were significantly higher at the development site in the summer. During the winter, water temperature, total dissolved phosphorus, phaeophytin, and dissolved zinc were higher at the development site. Dissolved oxygen (and oxygen saturation) and pH were the only parameters that were significantly higher at the refer-

ence marsh during both seasons. Chlorophyll and phaeophytin were significantly higher at the reference marsh during the summer, while the Fo/Fa ratio and dissolved iron were the only two parameters higher at the reference marsh for the winter sampling period.

87. The concentrations of some parameters changed with the ebb and flood tidal phases (Table 55). During both the summer and winter periods, dissolved oxygen (and oxygen saturation) were significantly higher at both marshes during the flood, while dissolved manganese was higher during the ebb tide. Only during the summer at both marshes was dissolved orthophosphate, iron, and volatile organic carbon significantly higher at ebb tide, while pH and chlorophyll were higher during the flood tide. There were fewer tidal effects in the winter with the exception of dissolved oxygen, water temperature, and phaeophytin, which were greater during the flood tide. There were some parameters that exhibited significant differences during the ebb and flood tidal periods because of the sampling location. The most important parameters at both marshes during both seasons were dissolved total phosphorus, dissolved calcium, and dissolved zinc (Table 55). Seven additional parameters showed significant differences between the four stations at the two marshes in the winter.

88 . The diurnal changes that occurred at the marshes were obviously water temperature, but more important were the significant day to night changes for ebb and flood samples during the summer for some biologically influenced constituents such as pH, dissolved oxygen, the Fo/Fa ratio, and phaeophytin. There was a significant variability in the concentrations of replicates (alpha and beta) during the ebb and flood tidal cycles for dissolved total phosphorus in the summer and dissolved orthophosphate, calcium, and zinc in the winter (Table 55).

89. The average clay/silt ratio for untreated suspended sediments at the reference marsh tidal channels during both seasons (2.5) was significantly greater than the ratio at the development site channels (1.0) (Figures 18 to 23). After the suspended sediments were treated with 30 percent H_2O_2, the average clay/silt ratio at the reference marsh tidal channels (1.4) was more nearly the same as that determined for the development site (0.9). This ratio at the reference marsh

channels was slightly higher than the clay/silt ratio of the H_2O_2 treated and dispersed sediments collected from the marsh substrate. However, the suspended sediments at the development site breach and pipes had the same ratio as sediments collected from cores within the development site (Table 31). Although the mean clay/silt ratio of untreated suspended sediments increased from summer to winter at the reference marsh, the mean ratio of only the H_2O_2 treated clay/silt fraction at the development site increased during this time period (Figures 19, 21, and 22). There were no consistent relationships between the clay/silt ratio and tidal phases or current velocities. Yet, more of the ebb tide samples were above the mean clay/silt ratio than were seen during the flood tide.

90. Like the clay/silt ratio at the reference marsh tidal channels, the CEC of the suspended sediments was significantly higher (151 meq/100 g) than that of the sediment substrate from within the marsh (66 meq/100 g; Tables 34 and 57). Similarly, the CEC of suspended sediments at the development marsh (99 meq/100 g in January) was significantly greater than the surface sediments within the confining dikes (32 meq/100 g; Table 34). While the ebb tide suspended sediment CEC was consistently greater than flood at the reference marsh for both seasons, the opposite was true at the development site, but only in the winter.

91. As explained in Appendix D', the mass import and export of each parameter was calculated for both channels at the two marshes during the summer and winter periods. These were computed for each of the four floods and ebbs, and net mass transport was derived for the entire 48- or 54-hour periods. Errors associated with the concentration measurements and the velocity portion of the volume calculations were at times larger than the net mass transport. These are noted in the tables, where the transport terms have also been normalized so that equal tidal volumes entered and left the two marshes. Only net mass export and import of variables that were significantly greater than the error terms are listed in Tables 58 and 59. There was significant export of dissolved volatile organic carbon, dissolved orthophosphate, and particulate copper at the breach and pipe of the development site during the summer,

while in the winter this was the case for dissolved total and volatile organic carbon, alkalinity, and possibly particulate cadmium (Table 58). There was also export of dissolved total nitrogen at the pipes and dissolved manganese and dissolved total phosphorus at the breach in the summer, yet in the winter dissolved mercury was the only parameter that indicated an export at the pipes. The situation was different at the reference marsh with seven parameters showing significant export at both channels in the summer and none in the winter (Table 58). Moreover, in the summer, there was significant export of dissolved volatile organic carbon, dissolved iron, and particulate lead at the small channel, while dissolved nitrate plus nitrite, dissolved total phosphorus, and particulate cadmium were exported at the large channel. In the winter, both dissolved total organic carbon and particulate cadmium were lost through the small channel.

92. Fewer of the measured parameters were imported to the marshes than were exported. Ten variables showed significant export at the development site during the summer and winter, while seven were imported. At the reference marsh, 14 variables were exported in summer and 11 in winter. During the summer there was significant import of dissolved oxygen at both channels of the development site, yet in the winter this seemed to be the case only for particulate manganese (Table 59). Only dissolved volatile organic carbon and particulate manganese showed significant import at both channels of the reference marsh during the winter. During the summer at the development site, net mass import occurred at the breach for particulate manganese and at the pipes for total phosphorus and dissolved zinc (Table 59). The same was true for suspended solids in the winter at the pipes and dissolved total nitrogen and orthophosphate at the breach. Dissolved total nitrogen was imported at the small channel of the reference marsh during the summer, while dissolved ammonium and particulate zinc indicated significant import at the large channel. There were six parameters that showed significant import at one of the channels of the reference marsh during the winter. Five of these were imported through the large tidal channel (Table 59) while at the small channel only one (alkalinity) was imported.

93. Numerous measured parameters exhibited net mass export at one channel and import at the other. This was the case for 14 variables at the development site in both summer and winter as compared to seven variables in the summer at the reference marsh and 12 in the winter (Table 60). In the summer, over twice the number of variables were exported through the pipes as compared to the breach, yet in the winter this was divided relatively evenly between the pipes (six variables) and breach (eight variables). However, at least double the number of variables were exported through the small channel at the reference marsh as compared to the large channel, regardless of season. Half of the net mass export valves at RS were significant during the two seasons (Table 60).

Discussion

94. Tidal studies conducted after vegetation was established at the development site, indicated negligible tidal mobilization of dissolved pollutants. Of the dissolved metals studied, only calcium, manganese, mercury, iron, and zinc, were within the detection limits (Table 5 in Volume I) and could be included in mass transport calculations. A small export (2.5 g) of dissolved mercury was calculated for the development site during the winter sampling program. Particulate copper, lead, and nickel were exported from the site during the August sampling period while cadium was the only exported metal detectable during the January sampling period. Export of these four metals from the reference marsh during the same sampling periods were greater, however, and ranged from 3 to 150 times higher. There was only 3 to 8 times less export of particulate copper and cadmium at the development site compared to the reference marsh but the mass export of copper was relatively high (124 g). Yet, the major portion of copper was probably associated with the sediment residual phases (Table 38) and would probably not be available for biological utilization. The phases for cadmium were not known. Because of the low recovery of suspended solids, particulate mercury was not measured. As pointed out later, the ratio of 3 to 8 for particulate Cu and Cd mass transport was also similar to intertidal surface substrate relationships

(Table 46). As discussed later, major losses from the development site were observed for dissolved total nitrogen and both volatile and total dissolved organic carbon.

95. With exception of the possible resuspension and introduction of particulate and interstitial water components from the large delta outside of the development site pipes, it was assumed that the flood waters entering the two marshes represented the background composition of James River or Herring Creek. From column three in Table 23 (Volume I) and the statistics in Appendix C', the composition of the source waters for these two marshes was relatively similar with exception to levels of conductivity and temperature in January and concentrations of suspended solids, dissolved manganese, and dissolved zinc in August. The mixing of flood waters with marsh sediments and interstitial waters and subsequent losses of various species to the overlying waters, as well as the addition of detrital components of vegetative origin from the marsh surface, would usually result in a net export from the marsh. Since exchange processes between interstitial and overlying tidal waters are considered to be of greater magnitude than sediment-water interactions during the 6-hour flooding period of the tide, it was expected that a large export indicated that such dynamic processes were taking place at the sediment-water interface (Hallberg et al. 1973) within the marshes. The transport of materials across this interface would certainly be increased by the actions of organisms, called bioturbation, and physical processes such as methane degrassing and mixing due to winds, rain, and currents.

96. At first it was thought that the physical location of sample collection sites at the pipe and breach of the development site as compared to the tidal channels at the reference marsh would jeopardize a proper interpretation of the data because of the height above the channel bottom, i.e., the reference marsh channels were approximately 1.5 - 2 m deeper than development sites. Since water samples in the reference marsh channels were collected 5 to 15 cm below the water surface, the concentrations of near surface samples (Cy) relative to near-bottom

concentrations (Ca) were calculated for suspended solids using the following equation:

$$\frac{Cy}{Ca} = \left[\frac{D-y}{D-a} \cdot \frac{a}{y}\right]^{z}$$

where a = 0.05 D or the depth of flow, y is the distance above the bottom at which the sample was collected, and $z = W/\kappa U^*$ (where $W/\kappa U^*$ is the average settling velocity of particles, κ is 0.4, the von Karman constant for a smooth bottom, and U^* is the shear velocity). The lowest ratio of Cy/Ca would occur at slack water where U^* approaches zero. If it is assumed that particles were all about 0.1-mm diameter, a value of 0.77 would be calculated for the Cy/Ca ratio. For dispersed particles of 5-μm diameter at slack water, this ratio would be 0.98 at a depth of 1 cm below the water surface. Thus, at least 77 percent of the maximum suspended solids concentration, with an average of about 90 percent, was collected near the surface of the two reference marsh channels.

97. There were obvious differences between the two marshes with respect to the concentrations of various parameters at the tidal channel. Those that exhibited significant differences during the ebb and flood tides are listed in Table 53, while mean concentrations at the tidal channels of the two marshes are provided in Tables 51 and 52. At least 70 percent of the parameters that exhibited significant differences showed higher concentrations at the development site. With the exception of suspended solids, total dissolved nitrogen, and chlorophyll in the summer, and water temperature, the Fo/Fa ratio, total dissolved phosphorus, and dissolved zinc in the winter, 13 other parameters listed in Table 53 were significantly different between the two marshes during both seasons. Except for particulate metals, these represented half of the measured parameters. It was possible that these differences were due to the natural variability of such freshwater marshes rather than the composition of the recently dredged substrate that constituted one of the sites. It is obvious that future experimental designs should include at least two natural marshes in order to test such interpretations. Because the marsh surface was slightly frozen during the winter sampling

program, very little resuspension of the marsh substrate and a decrease in the transport of dissolved components across the sediment-water interface would have certainly occurred. This was most noticeable as a decrease in suspended solids and turbidity of the water leaving the marshes (Table 51) as well as the number of variables that were exported seasonally, especially at the reference marsh (Table 58).

98. The mobilization and export of different components, whether natural or of a pollutant nature, would be a function of the area of marsh surface inundation during each tide, the difference in concentration between the overlying tidal water and sediment interstitial water, and the rate of transport between the marsh substrate and the overlying waters. The relationship of tidal volume to area of water inundation would be most important since mobilization across marsh substrates would effect the quantity of mass export. For tides above one meter, the ratio of surface areas was about 4 to 1 (reference to development site) and decreased to a minimum of 3.6 to 1 for the highest tides (Table 46). Below one meter, this ratio increased more rapidly in 1976 than it did in 1977, where at about 0.75 meter it varied from 16 to 1 (1976) to 6 to 1 (1977) and at 0.5 meter from 10,200 to 1 (1976) to 390 to 1 (1977). This investigation did not address the relationships between mass transport and tidal inundation of marsh substrates with respect to recently dredged substrates versus natural well-established freshwater marshes. However, a 4 to 1 ratio for tidal inundation between the two marsh surface substrates could be applied as a first approximation to the net mass transport values listed in Tables 58 to 62. The tidal prism volume relationships between the two marshes changed from about 7.8 to 1 (reference to development site) in August 1976 to 5.7 to 1 for January 1977 (Tables 49 and 50) as a result of substantial intertidal erosion at the development site during the period between topographic surveys.

99. The lack of a significant export of suspended solids during both sampling periods at the development site was puzzling. It was possible that resuspension of delta material outside the pipes during the flood distorted the calculation of net mass transport and also provided an apparent import of suspended sediments. Regardless, there was a sig-

nificant export of particulate copper and possibly iron at the development site in the summer and particulate cadmium in the winter (Table 58). The export of particulate cadmium was very small, however, and averaged only 0.9 $\pm$ 0.3 g over the four tidal cycles. Other particulate metals exported at the development site were calcium and lead in the summer. Three of the particulate metals were imported in the summer (manganese, zinc, and cadmium) as compared to the winter import (manganese, iron, calcium, zinc, copper, and lead; Table 61). The export of particulate copper (summer) and cadmium (winter) occurred in about the same ratio as the area of inundation between the two marshes. Particulate copper export might have been slightly higher at the development site. In addition, there was an export of particulate nickel, lead, and cadmium at both channels of the reference marsh (Table 58) and particulate iron and calcium at one channel in the summer. Particulate zinc was the only metal imported in the summer at the reference marsh, with the exception of manganese, which will be discussed later. Particulate manganese, iron, calcium, lead, and copper were imported through both channels at the reference marsh in the winter, while particulate nickel showed a larger winter export than net mass import.

100. With exception of Ca, Fe, Mn, Zn, and Hg, the dissolved concentrations of the other metals were below detection limits (Table 5 in Volume I). Particulate Hg was not measured in the suspended sediments. The greatest transport of iron was in the particulate phase, where values exceeded dissolved net mass transport by 3 to 60 times (Table 61). Calcium and zinc, however, existed in the dissolved phase, where solution exceeded particulate transport by 3 to 94 for calcium and 1.6 to 34 for zinc. The greatest differences between dissolved and particulate transport occurred at the reference marsh. This probably reflected the larger volume to surface area of the reference marsh. There were seasonal changes in the net mass transport of manganese, where dissolved export exceeded particulate import by 1.3 to 6.5 times in the summer at both marshes, and particulate import exceeded dissolved export by 2.5 to 15.5 times in the winter (Table 61). Six of the nine metals were exported

from the development site in the summer, while all nine exhibited a greater export at the reference marsh. However, the situation was reversed during the winter sampling period where seven of the nine metals were imported into both the development site and reference marsh. If both dissolved and particulate phases were combined and the two sampling intervals were considered to represent the entire annual periods of growth and dormancy of the marshes, a balance between export and import existed for Ca, Fe, Pb, Mn, Hg, and Ni at the development site and only Mn at the reference marsh. During August and January there was a greater import of both phases of zinc into the development site, possibly in response to biological utilization during the initial very productive 2 years. Over both seasons, copper was exported in the particulate phase to a larger extent than it was imported. This was also the case at the reference marsh, where during both seasons there was a larger overall export of Cd, Pb, Hg, Ni, and Zn as well as Cu (only the particulate phases were used for the transport calculation because dissolved phases with exception of Zn, were below detection). Suspended sediments at the reference marsh tidal channels also exhibited higher CEC measurements than at the development site, which suggested that at least a portion of the transport was associated with this fraction. In contrast, only Ca and Fe were shown to exhibit a greater overall import during both seasons at the reference marsh if both dissolved and particulate phases were considered.

101. As shown in Part II, there was a substantial difference between the two marshes in total manganese concentration in the sediments (Table 30) with values at the reference marsh measuring only one-third of those at the development site. It was suspected that Mn was mobilized from sediment phases into the interstital water dissolved phase and was eventually lost to the overlying tidal waters. Since both marshes were intertidal, the difference in total Mn was attributed to the longer period of tidal flooding and flushing at the reference marsh (200+ years) as compared to the development site (2 years). Data presented in Tables 58 to 61 certainly substantiated this interpretation: dissolved Mn was lost from both marshes during August and January. Because of its relatively slow oxidation rate (Stumm and Morgan 1970),

exported dissolved Mn (II) was eventually transformed into various insoluble phases and measured as imported particulate Mn (Table 61). Because of increased bioturbation and bacterial processes in the summer, export was higher from both marshes than in the winter. This is also seen (Table 56) as seasonal differences in flood and ebb tidal cycles at the pipes. The net mass export ratio of 3.5 to 1 (reference to develment site) of dissolved Mn during the ebb tide compared favorably to the substrate ratio of 4 to 1 (reference to development site) for tidal inundation. The loss of dissolved Mn(II) to the tidal waters was also observed as a seasonal phenomenon that was closely related to the larger source of dissolved manganese during the summer. Concentrations in the particulate phase averaged 2,000 $\mu g/g$ in the summer, while during the winter period of low biological activity (and thus less dissolved Mn transport across the sediment-water interface) particulate phase Mn averaged 600 $\mu g/g$ (Appendix B'). This was also the case for dissolved iron during the summer at both marshes, except that it was exported from the marsh in both dissolved and particulate phases. The tidal inundation substrate ratio of 4 to 1 between the reference and development marshes did not apply, as was the case with Mn, to the export of Fe in the dissolved phase (34 to 1). This suggested that either iron export was restricted at the development site due to precipitation as ferric phosphates, hydroxides, and oxides or that the chemical cycle of dissolved iron cannot be closely related to manganese, at least with respect to these two marshes. The concentration of interstitial phosphate in the development site sediments was, however, double the values measured at the reference marsh in the summer (Table 28), and therefore greater $FePO_4$ precipitation in the upper oxidized zone of the sediments could occur. As shown later, these compounds might be present as colloidal material which cannot be partitioned by membrane filtration. Perhaps maturation and complexation of iron with natural organic chelators or as polymerized ferric hydroxo complexes (Hallberg et al. 1973) were important for its mobilization. Even though the percentages of Fe and Mn were similar in the sediment organic phase (Table 38), the overall abundance of iron was much greater and would therefore allow for a different magnitude of transport across the sediment water interface. Therefore, transport in the dissolved phase could have been higher at the reference marsh and provide a ratio of 34 to 1 (reference to development site; Table 61) since dissolved Fe(III, II)-organic chelates and complexes or Fe(III) hydroxo sols exhibit a greater resistance to oxidation and eventual precipitation than would dissolved ferrous iron species. As with Mn, the average concentration of Fe in the particulate phase was higher in the summer (about 50,000 μg/g) than in the winter (36,000 μg/g; Appendix B').

102. Concentrations of organic and inorganic electrolytes in solution, measured by conductivity, are closely related to the bacterial processes of organic decomposition. Kuznetsov (1970) reported maximum values in the summer for the bottom waters of Russian lakes as a result of the release of microbial decay products from bottom silts. Conductivity measurements were always higher in the tidal channels at the development site as compared to the reference marsh. This situation persisted into the winter period at the development site, and yet this was not the case at the reference marsh tidal channels (Tables 51 and 52). This indicated that bacterial decomposition was still occurring during the winter sampling period at the development site or that the sediments continued to leach decay products that had built up from the previous fall. As shown previously, this was also evident as a continual, albeit lower, loss of dissolved manganese from the two marshes in the winter; yet, if the two marshes were compared there was a substantially greater loss from the development site as compared to the reference site (Table 61; change from 3.5 to 1 mass export ratio in the summer to unity in the winter). Dissolved volatile organic carbon compounds, which are liberated during the initial stages of anaerobic decomposition (Foree and McCarty 1970, Otsuki and Hanya 1972, and Adams 1973), exhibited a net export during both seasons at the development site, yet were lower in the winter. It should be noted, perhaps fortuitously, that the net import of dissolved oxygen at the development site balanced the export of dissolved volatile organic carbon. The liberation of these compounds from the recently dredged substrate probably represented

a substantial portion of the oxygen demand since these compounds would be excellent substrates for bacterial utilization. This is obviously an area for future studies. During both seasons, dissolved total organic carbon* was exported from both marshes during August and January. The volatile portion of the dissolved organic carbon compounds was about 25 percent for the development site tidal waters and 15 percent at the reference marsh. This represented a substantial loss of DOC from both marshes that was not reflected in changes to the bulk carbon content of the marsh sediments (Table 28). The unusually large export of DOC during the winter probably reflected three high concentrations during the pre-precipitational ebb period at the small channel of the reference marsh (Figure A'74). In fact, volume normalized net mass export was 368 kg at RS compared to 146 kg at RL, which was abnormal. If the DOC mass associated with the last ebb and flood cycles were removed from the transport calculations at RS in January, the net export through the small channel was about 13 kg and would provide a winter DOC loss of 159 kg from the reference marsh rather than 514 kg. A rain storm that occurred before the last ebb tide probably flushed the marsh's surface of accumulated dissolved organic products. The spring and early summer periods were not sampled, therefore an annual budget would be difficult to ascertain. Axelrad et al. (1976) reported annual net losses of both dissolved and particulate carbon from two saltwater marshes on the York River, Virginia. They observed a loss of 6.5 times as much POC during a July thunderstorm as was recorded during the next highest period of export. However, this was not the case with POC for the two James River marshes, probably because of the lack of vegetation in January.

103. As shown in Volume I, the relationships of dissolved ammonium to total dissolved nitrogen provided information concerning organic decomposition within the interstitial water of the James River channel

* It should be remembered that the measurement of dissolved total organic carbon includes dissolved volatile organic carbon as a portion of the total, and that these were treated as such for the calculation of mass transport. The same would also apply to TKN, TDN, TP, and TDP for water samples collected during the August and January tidal studies.

sediments as well as an indication of tidal mixing with nutrient-enriched sediment pore water during the early stages following containment of the dredged sediments. Dissolved phosphate was about 47 percent of TDP (PO_4/TPD = 0.47) in the upper section of the channel cores and increased to an average of 0.61 with depth, probably as a result of bacterial decomposition of dissolved organic phosphorus compounds to dissolved inorganic orthophosphate as an end-product. However, dissolved ammonium was about 90 percent of TDN (NH_4/TDN = 0.90) in the surface half meter of sediments and was relatively constant with depth, indicating that decomposition of nitrogen compounds to inorganic NH_4 was relatively rapid. In May 1975 (3.5 months post-dredging), the PO_4/TDP and NH_4/TDN ratios were 0.5 and 0.6, respectively, during low tide sampling at the pipes, while the contribution of dissolved phosphate and ammonium to the total dissolved components decreased substantially during high tide (PO_4/TDP = 0.3 and NH_4/TDN = 0.2). In August 1976, water samples collected during the pore water drainage tidal phase at the pipe had the same composition (PO_4/TDP = 0.76; NH_4/TDN = 0.22) as the development site sediment interstitial water (PO_4/TDP = 0.74; NH_4/TDN = 0.21). During August, the percentage of dissolved phosphate increased during the ebb tide at the development site (PO_4/TDP = 0.86) above that of the pore water, while during the flood it diminished (0.66). Perhaps orthophosphate existed along with ferric iron as colloidal substrates (Stumm and Morgan 1970) in the surface sediments, which could not be separated by membrane filtration. Upon analysis, this fraction would provide a higher PO_4/TDP ratio for the ebb tide than would normally be present in the interstitial waters or by mixing of tidal waters with the former. Dissolved phosphate and TDP were exported from both marshes in the summer (Table 62). Even though the concentration of TDP was higher in the sediment interstitial waters at both marshes, the export of dissolved phosphate was greater perhaps as a result of such interaction of tidal waters with surface Fe(III) hydroxo-phosphate colloidal material. With the exception of pore water drainage at the development site, the NH_4/TDN ratio of the ebb and flood was 0.11 and 0.14, respectively, or about half the August 1976 sediment interstitial water composition (0.21).

104. A greater amount of dissolved orthophosphate, as compared to TDP, was seen in the tidal waters (flood = 0.45, ebb = 0.51) of the reference marsh in the summer than would have been predicted as loss from the sediment interstitial waters (PO_4/TDP = 0.33). This either suggested an outside source or, as with the development site, a greater mobility of dissolved colloidal phosphate compounds from the sediments. Since there was a net export of both PO_4 and TDP during the summer, the latter was most likely the case especially since the two parameters exhibited a ratio of 0.85 for their mass exports (Table 62), which was well above the tidal or interstitial water composition ratios. An outside source for dissolved ammonium was suspected at the reference marsh in the summer because both the NH_4/TDN ratio was 0.27-0.38 as compared to sediment porewater composition of 0.16 and each of the two parameters indicated a net mass import. It was possible that the large export of 292 kg of TKN was partially decomposed outside the marsh in Herring Creek and returned as dissolved total nitrogen and ammonium (Table 62). This situation was quite different in winter than in summer conditions, yet there was a similarity at both marshes. Sediment interstitial water had the same composition at both sites in the winter (PO_4/TDP = 0.50 to 0.55; NH_4/TDN = 0.51 to 0.53), while tidal channels at the development site and reference marsh exhibited lower ratios. Porewater drainage was no different than other tidal stages at the development site (PO_4/TDP = 0.37 to 0.41; NH_4/TDN = 0.15 to 0.19). The total component of dissolved phosphorus and nitrogen compounds at the reference marsh tidal channels averaged 34 percent dissolved phosphate (0.34 ratio) and 17 to 20 percent dissolved ammonium (0.17 to 0.20 ratio) which was similar to the development site. This suggested that there was little exchange between the sediment interstitial waters and overlying tidal waters during the winter. This could be due to both the lack of bioturbation and the frozen marsh surface sediments.

105. From mass transport calculations of the different nitrogen species at the development site, it was most likely that the rapid depletion in bulk TKN from an average of 3,376 µg/g in July 1975 (6 months post-dredging) to 765 µg/g 13 months later (Table 28) was

partially caused by the mobilization and export of total dissolved nitrogen compounds and not dissolved ammonium. The same was observed by Nixon et al. (1976a) for nitrogen loss from bottom sediments in Narragansett Bay, Rhode Island, where at least half of the flux was in the form of dissolved organic nitrogen. Aerobic nitrification of dissolved ammonium also led to some export of nitrate plus nitrite (Tables 58 and 62). The decomposition of TDN in the waters outside of the development site resulted in a slight import of dissolved ammonium. Losses of N_2 and N_2O during dentrification were not measured. There was a greater export than import of nitrogen from the reference marsh, an observation also made by Axelrad et al. (1976) for two marshes on the York River, Virginia. These authors also stated that particulate nitrogen was exported only during the fall and winter seasons. This was the case for TKN measurements at the reference marsh (Table 62), which would imply that such processes might be reversed in the spring and early summer. Contrary to findings by Axelrad et al. (1976) with respect to TDN compounds and (Woodwell et al. 1976) for dissolved ammonium, both of these measured parameters were imported to the reference marsh in the summer. However, there was export from the reference marsh of both parameters in the winter, which is in agreement with results from the York River marshes (Axelrad et al. 1976). As substantiated by further studies at Flax Pond by Woodwell et al. (1977), the reference marsh was a net consumer of phytoplankton during both seasons. This was also the case for the development site during the summer sampling period as seen by the net mass import of chlorophyll (Table 62).

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Table 26

Summary of Collections for the 7-cm Diameter Sediment Cores and Surface Samples During Various Field Studies at the James River Artificial Habitat Development Site and a Reference Marsh

Date	Total Number of Cores	Number of Sites from Which Cores Were Collected		Purpose
		Habitat	Reference	
July 1975	14	7	—	Probe analysis
	6	3*	—	Probe analysis and chemistry
	11	11	—	Mineralogy, size and physical description
July 1976	19 (surface samples)	19	—	CEC
August 1976	1	—	1	Physical description
	18	3*	3*	Probe analysis, chemistry, CEC and size
January 1977	18	3*	3*	Probe analysis, chemistry and CEC
June 1977	4	2	—	CEC, special studies

* Locations which were divided into high marsh, intertidal, and subtidal

Table 27

Summary Statistics for Field Observations (Temperature, pH, and Eh), Percent Water, and Volatile Solids for Sediments from the Artificial Habitat Development Site and a Reference Marsh, James River, from July 1975 to January 1977. Channel Data are Provided as a Comparison

Parameter	Statistic	James River Channel January 1975	Artificial Marsh July 1975	Artificial Marsh August 1976	Artificial Marsh January 1977	Reference Marsh August 1976	Reference Marsh January 1977
Temperature (°C)	Mean	13.6	21.8	23.1	- 1.2	24.3	0.5
	Std. Dev.	2.9	3.7	1.5	3.9	2.0	1.3
	Number	22	13	18	18	18	18
pH	Mean	6.70	6.78	6.61	6.73	6.19	6.24
	Std. Dev.	0.22	0.40	0.35	0.31	0.49	0.55
	Number	21	13	26	23	24	26
Eh* (mV)	Mean	-25	+72	+ 105	+ 124	+ 128	+ 173
	Std. Dev.	54	110	100	117	53	43
	Number	22	13	25	23	26	26
Water (%)	Mean	50.8	38.7	47.0	44.2	66.1	67.9
	Std. Dev.	6.4	15.5	14.9	11.8	12.8	10.7
	Number	21	12	17	18	18	18
Water (%) (0-5 cm)	Mean	54.8	50.6	56.1	49.3	70.3	75.9
	Std. Dev.	5.4	9.6	7.9	11.1	13.7	6.0
	Number	10	26	9	9	9	9
Volatile Solids (%)	Mean	14.5	--**	7.2	7.8	15.1	16.6
	Std. Dev.	1.9	--	3.4	3.1	6.3	6.3
	Number	20	--	17	18	18	18
Volatile Solids (%) (0-5 cm)	Mean	13.8	4.9	10.9	8.9	17.4	19.2
	Std. Dev.	1.4	1.0	1.5	2.3	7.7	7.7
	Number	10	26	9	9	9	9

* Corrected for the potential of the saturated calomel electrode

** Not measured over entire depth of cores collected in July 1975

Table 28

Summary Statistics for Interstitial and Total Nutrients and Organic Carbon for Sediments from the Artificial Habitat Development Site and a Reference Marsh, James River, from July 1975 to January 1977. Channel Data are Provided as a Comparison

Parameter	Units	Statistic	*James River* Channel	*Artificial Marsh* July 1975	August 1976	January 1977	*Reference Marsh* August 1976	January 1977
INTERSTITIAL								
TDP	mg/l	Mean	0.456	0.222	0.136	0.139	0.180	0.164
		Std. Dev.	0.153	0.081	0.047	0.024	0.084	0.027
		Number	20	12	18	17	21	22
ortho-PO_4	mg/l	Mean	0.252	0.054	0.100	0.076	0.059	0.082
		Std. Dev.	0.152	0.010	0.020	0.012	0.010	0.013
		Number	20	12	18	19	19	24
TDN	mg/l	Mean	69.66	34.22	12.66	5.56	10.16	3.52
		Std. Dev.	14.92	14.12	8.14	2.41	9.65	1.21
		Number	20	12	18	17	21	22
NH_4	mg/l	Mean	63.49	31.46	2.65	2.96	1.59	1.79
		Std. Dev.	12.50	8.40	1.89	1.25	1.21	0.52
		Number	43	10	18	19	20	24
$NO_3 + NO_2$	mg/l	Mean	0.064	0.024	0.100	0.106	0.119	0.104
		Std. Dev.	0.018**	0.009	0.020	0.049	0.047	0.052
		Number	20	12	18	19	19	24
DOC	mg/l	Mean	*	60.6	36.3	19.9	28.4	16.2
		Std. Dev.		16.0	15.6	7.1	14.1	4.6
		Number		11	26	24	25	25
TOTAL								
TP	µg/g	Mean	662	814	746	690	666	648
		Std. Dev.	110	58	311	328	407	416
		Number	39	16	27	24	25	25
TKN	µg/g	Mean	4,577	3,376	765	531	1,540	1,010
		Std. Dev.	684	707	360	285	823	398
		Number	39	16	27	24	25	25
TOC	µg/g	Mean	*	17,140	10,400	12,170	12,000	12,750
		Std. Dev.		1,590	2,050	1,950	2,460	2,176
		Number		11	27	24	25	25

* Not measured in channel sediments

** Standard deviation calculated for dissolved nitrate only

Table 29

Summary Statistics for Interstitial Metals (mg/l)* for Sediments from the Artificial Habitat Development Site and a Reference Marsh, James River, from July 1975 to January 1976. Channel Data are Provided as a Comparison

Parameter	Statistic	James River Channel	Artificial Marsh July 1975	Artificial Marsh August 1976	Artificial Marsh January 1977	Reference Marsh August 1976	Reference Marsh January 1977
Ca	Mean	215.9	60.6	81.5	65.2	26.5	13.4
	Std. Dev.	59.3	25.8	28.7	33.0	18.6	9.0
	Number	44	30	20	18	21	25
Fe	Mean	57.3	23.9	30.7	20.8	33.7	12.3
	Std. Dev.	26.7	12.6	16.6	14.4	26.1	10.9
	Number	44	30	20	18	21	25
Mn	Mean	6.94	2.68	3.82	2.84	1.44	1.27
	Std. Dev.	3.88	1.22	1.37	1.22	1.12	1.28
	Number	44	29	20	18	21	25
Zn	Mean	0.120**	0.322	0.063	0.056	0.075	0.053
	Std. Dev.	0.190	0.286	0.069	0.040	0.045	0.028
	Number	31	29	20	18	21	25
Cu	Mean	0.012	†	0.029	††	0.045	††
	Std. Dev.	0.014		0.029		0.049	
	Number	36		17		5	
Cr	Mean	‡	††	0.034	††	0.035	††
	Std. Dev.			0.009		0.014	
	Number			6		9	
Hg*	Mean	3.2	‡‡	5.6	0.8	4.0	0.6
	Std. Dev.	2.0		5.5	0.6	2.7	0.2
	Number	24		18	17	20	25

* Mercury concentrations are listed as μg/l

** Three (3) data greater than 1 mg/l were rejected as being nonrepresentative

† Quantity of water sample was not sufficient for the analysis of this metal

†† Below detection for specific metal

‡ Chromium was not measured in the channel sediments

‡‡ Not measured because of sample storage time

Table 30

Summary Statistics for Total Metals ($\mu g/g$) for Sediments from the Artificial Habitat Development Site and a Reference Marsh, James River, from July 1975 to January 1977. Channel Data Are Provided as a Comparison

Parameter	Statistic	James River Channel	Artificial Marsh July 1975	Artificial Marsh August 1976	Artificial Marsh January 1977	Reference Marsh August 1976	Reference Marsh January 1977
Fe	Mean	40,780	38,710	33,630	36,170	38,530	35,340
	Std. Dev.	8,100	11,870	10,380	8,184	11,950	6,870
	Number	25	16	27	24	25	25
Ca	Mean	4,100	3,030	2,830	3,140	3,310	2,100
	Std. Dev.	674	973	1,440	660	1,250	800
	Number	20	16	7	24	24	24
Mn	Mean	1,100	902	914	887	318	340
	Std. Dev.	204	263	280	180	109	207
	Number	25	16	27	24	25	24
Zn	Mean	240	188	182	190	224	186
	Std. Dev.	55	70	60	50	142	72
	Number	24	16	27	24	25	25
Pb	Mean	62.2	58.2	51.1	57.7	55.3	55.2
	Std. Dev.	14.3	21.9	17.8	17.7	17.5	17.0
	Number	25	16	27	24	25	24
Cr	Mean	*	71.3**	62	40	64	40
	Std. Dev.		0.0	14	9	10	7
	Number		1	20	24	25	25
Cu	Mean	49.0	41.4	40.2	40.9	45.4	41.1
	Std. Dev.	13.8	15.8	13.5	12.7	14.8	10.5
	Number	25	16	27	24	25	24
Ni	Mean	33.5	35.1	29.6	32.4	36.4	42.8
	Std. Dev.	7.5	12.9	9.5	9.1	5.3	3.2
	Number	25	16	27	24	25	24
Cd	Mean	1.32	1.54	1.33	1.46	1.16	1.24
	Std. Dev.	0.56	0.56	0.47	0.43	0.39	0.32
	Number	25	16	27	24	25	25
Hg	Mean	0.52	0.21	0.23	0.23	0.21	0.23
	Std. Dev.	0.17	0.10	0.08	0.08	0.12	0.25
	Number	19	15	27	24	25	25

* Cr was not measured in the James River channel sediments

** One sample from the middle of a core at site AI (Artificial Habitat intertidal location)

Table 31

Summary Statistics for Average Size Parameters for All Sampling Locations at the James River Artificial Habitat Development Site and a Reference Marsh, the James River Channel, and Suspended Sediments

Sample Location	Number of Samples	Mean ϕ Size	ϕ Sorting	Skewness	% Silt	% Clay	Primary Mode ϕ	Secondary Mode ϕ	Third Mode ϕ
Channel Cores (0 - 20 cm) January 1975	10	7.8	2.9	0.13	50.8	44.1	7.4	9.0	4.7
Artificial Habitat	23	7.9	3.0	0.15	49.6	43.4	6.9	8.6	5.0
Reference Marsh	27	9.0	2.9	-0.15	33.1	60.5	6.8	5.3	4.6
Suspended Sediment at Pipe During Active Dredging	8	7.7	2.9	0.22	51.7	40.4	7.2	5.1	
Suspended Sediment at Pipe 3.5 Months After Dredging	7	8.7	2.5	0.05	43.6	55.6	8.5	6.2	

Table 32

Estimates of Clay Mineral Abundances for the Clay and Silt Size Fractions of Sediments from the James River Artificial Habitat Development Site, a Reference Marsh, the James River Channel, and Nearby Cliffs of Tertiary Age on the South Shore, Approximately 3 km Upstream of the Habitat

Location	Size Fraction (μm)	Illite	Expandable Mixed-Layered	Chlorite	Vermiculite	Smectite	Kaolinate	Estimated CEC meq/100 g
Intertidal Reference Marsh (RI)	0.2-2	33	34	<1	<1	0	32	34
	<0.2	18	41	12	14	6	8	59
High Marsh Artificial Habitat (AH)	0.2-2	37	18	20	0	0	22	28
	<0.2	35	15	0	0	1	49	24
Average Channel	<2	41	12	23	10	8	5	45
Cliffs Along River	<2	57	5	8	12	9	9	45
Average CEC Used For Estimates (meq/100 g)		25	65	25	125	105	9	

Table 33

Average Heavy Mineral Percentages* at the James River Artificial Habitat Development Site and a Reference Marsh

Mineral	Percentage at Artificial Habitat	Percentage at Reference Marsh	Relative Stability
Zircon	4	2	
Tourmaline	14	5	Ultrastable
Rutile	Tr**	Tr	
Staurolite	9	1	
Sillimanite	1	2	
Kyanite	9	3	
Andalusite	6	12	Stable
Sphene	1	6	
Monazite	4	Tr	
Epidote	12	19	
Garnet	1	4	Unstable
Hornblende	16	9	Very Unstable
Opaques	24	33	
Fraction of Total Sediment	0.23	0.11	

* These percentages are number percents based on point counts of 0.062-0.125 mm grains denser than 2.9 g/cc. Surface samples from sites AI and AS (July 1975) and RH and RS (January 1977) were used for these counts

** Tr = trace (less than 0.5 percent)

Table 34

Average Cation Exchange Capacities, as meq/100 g NaEC for Unfractionated Total Samples, from the James River Artificial Habitat Development Site and a Reference Marsh for August 1976 and January 1977

Season	Location	Statistic (n=3)*	Artificial Habitat (0-10 cm)	Artificial Habitat (24-50 cm)	Reference Marsh (0-10 cm)	Reference Marsh (24-50 cm)
Summer	High Marsh (AH & RH)	Mean	6.0	9.9	88.8	61.5
		Std. Dev.	1.0	2.4	5.2	4.3
	Intertidal Marsh (AI & RI)	Mean	46.6	33.0	52.1	48.6
		Std. Dev.	4.8	3.4	8.3	8.8
	Subtidal Marsh (AS & RS)	Mean	43.9	43.3	60.6	65.0
		Std. Dev.	2.1	1.9	1.2	3.4
	All Summer Samples	Mean	32.2	28.7	67.2	58.4
		Std. Dev.	19.8	15.0	17.3	9.1
Winter	High Marsh (AH & RH)	Mean	20.7	19.6	96.0	47.4
		Std. Dev.	3.1	6.6	30.9	3.6
	Intertidal Marsh (AI & RI)	Mean	38.1	33.5	57.0	41.3
		Std. Dev.	1.8	1.7	12.4	5.1
	Subtidal Marsh (AS & RS)	Mean	41.1	38.9	50.6	58.9
		Std. Dev.	8.1	4.3	8.1	10.7
	All Winter Samples	Mean	32.9	29.9	64.6	49.9
		Std. Dev.	10.6	9.8	25.5	10.7

* The three samples were from separate cores taken within a 25 m^2 area, and each sample was analyzed in duplicate.

Table 35

Variations in Sediment CEC with Various Size Fractions, Freeze-Drying, and Saturating Ions from the Same Samples Collected in July 1975 or July 1976 at the James River Artificial Habitat Development Site

Treatment	Mean meg/100 g	Std. Dev. meg/100 g	n	Change with Respect To First Line (%) Mean	Std. Dev.
Bulk, Wet, NaEC	33.2	4.2	5	—	—
<2μm, Wet, NaEC	65.7	25.3	3	+80	59
<2μm, Freeze-Dried CaEC	35.2	11.0	6	+10	45
<62μm, Wet, NaEC	33.7	5.7	12	- 8	13
<62μm, Freeze-Dried NaEC	22.9	2.6	6	-30	14

Table 36

Temporal Changes in Cation Exchange Capacity, as meq/100 g NaEC for Selected Samples, from the James River Artificial Habitat Development Site

Size Fraction	Date of Collection	Statistic	(100,400)*	(100,300)	(225,125)	(200,300)	(1100,100)
			Sample Location (x,y)				
Total	July 1975	Mean	—	29.0	32.6	—	38.1
		Std. Dev.		3.2	1.8		—
		Number		2	2		1
<62μm	July 1975	Mean	—	28.2	34.0	—	29.8
		Std. Dev.		0.1	1.2		3.3
		Number		2	2		2
<62μm	July 1976	Mean	41.5	41.3	49.8	44.9	34.5
		Std. Dev.	1.3	2.5	—	5.4	3.3
		Number	2	2	1	2	4
Total	August 1976	Mean	6.0	—	—	46.6	43.9
		Std. Dev.	1.0			4.8	2.1
		Number	3			3	3
Total	January 1977	Mean	20.7	—	—	38.1	41.1
		Std. Dev.	3.1			1.8	8.1
		Number	3			3	3
Total	June 1977	Mean	—	—	—	29.3	30.2
		Std. Dev.				2.3	1.3
		Number				2	2

* Bulk samples from AH (high marsh site) contained variable amounts of sand which reduced the CEC proportionately to the percent of sand

Table 37

Summary Statistics for the Change in Cation Exchange Capacity, as meq/100 g NaEC with Removal of Organic Matter and Iron Coatings, for Sediments from the James River Artificial Habitat Development Site and a Reference Marsh

Size Fraction	Marsh	Collection Date	Statistic	Untreated Wet	Organics Removed	Δ%	Organic Matter and Iron Coatings Removed	Δ%
<62μm	Habitat	July 1975	Mean	30.4	19.1	-36.5	19.8*	-34.0
			Std. Dev.	2.9	2.5	11.4	3.2	14.8
			Number	6	6	6	6	6
<62μm	Habitat	July 1976	Mean	37.1	29.6	-27.2	21.8	-40.4
			Std. Dev.	6.9	3.8	11.0	1.6	7.1
			Number	6	4	4	6	6
Total	Habitat	Jan 1977	Mean	34.6	15.0	-61.4	13.7	-60.3
			Std. Dev.	9.4	3.9	4.4	3.5	2.4
			Number	10	10	10	10	10
Total	Reference Marsh	Jan 1977	Mean	62.4	22.8	-60.8	21.3	-63.2
			Std. Dev.	27.7	4.4	9.4	4.2	9.4
			Number	12	12	12	12	12

* Iron coatings only removed.

Table 38

Concentrations and Average Percentages of Metals Associated with Different Fractions of the Sediments from the James River Artificial Habitat Development Site and a Reference Marsh

(Data are from Nivens (1978) for Cores Collected in August 1976)

	IRON		CALCIUM		MANGANESE		ZINC		LEAD		COPPER		NICKEL	
Fractions	Art*	Ref*	Art	Ref	Art	Ref	Art	Ref	Art	Ref	Art	Ref	Art	Ref
Interstitial water (mg/l)	22.8 (16.7)**	22.7 (21.4)	78.1 (33.2)	21.2 (15.3)	3.74 (1.94)	1.56 (1.46)	0.060 (0.034)	0.067 (0.038)	BD†	BD	BD	BD	BD	BD
Exchangeable (%)	0.26 (0.44)	0.44 (0.93)	40.4 (11.2)	68.6 (27.0)	18.1 (12.8)	29.6 (14.0)	7.56 (9.54)	8.56 (8.25)	BD	BD	BD	BD	BD	BD
Easily reducible (%)	5.34 (2.64)	5.52 (3.98)	17.6 (6.15)	11.1 (4.59)	44.8 (11.6)	24.6 (37.8)	25.1 (11.6)	19.6 (20.2)	BD	BD	11.7 (9.43)	6.86 (7.75)	4.22 (6.42)	1.07 (2.19)
Organic (%)	2.27 (2.19)	3.16 (1.57)	8.03 (3.76)	7.48 (3.50)	16.2 (8.78)	12.7 (10.6)	12.0 (17.8)	14.1 (11.2)	7.43 (6.20)	4.99 (6.77)	11.2 (8.54)	17.7 (10.2)	8.85 (7.62)	9.83 (7.30)
Moderately reducible (%)	46.51 (16.0)	46.3 (21.4)	0.90 (0.59)	0.413 (0.312)	8.59 (1.50)	11.1 (10.5)	15.6 (4.58)	14.3 (4.21)	33.7 (12.3)	38.6 (21.5)	BD	BD	BD	BD
Residual (%)	45.6 (9.92)	44.8 (4.67)	33.1 (16.8)	12.4 (4.96)	12.2 (3.29)	22.0 (5.69)	39.8 (12.8)	43.4 (12.3)	58.8 (16.9)	56.4 (14.8)	77.1 (32.0)	75.4 (21.1)	86.9 (26.0)	89.1 (11.2)
Total by summation (μg/g)	33,800 (9,400)	36,400 (8,900)	3089	2420	745 (187)	320 (195)	208	225	49.8	51.3	40.6 (14.4)	42.8 (13.5)	31.8 (9.81)	42.3 (4.01)
Total by bulk analysis (μg/g)	34,500 (7,690)	37,300 (11,500)	2979 (654)	2900 (966)	888 (174)	388 (231)	187 (46.4)	197 (100)	52.2 (14.2)	51.8 (18.1)	40.4 (10.2)	42.1 (14.0)	30.0 (7.89)	39.0 (5.68)

* Art = Artificial Habitat Development Site; Ref = Reference Marsh near Ducking Stool Point

** ±1 sigma, expressed in designated units (mg/l, %, or μg/g)

† BD = Below detection for specified metal

Fractions or phases defined as:

Interstitial - by centrifugation (in nitrogen atmosphere)
Exchangeable - removed from cation exchange sites by NH_4OAc leach (in nitrogen atmosphere)
Easily reducible - extract hydrous manganese oxides and hydroxides with $NH_2OH \cdot HCl$
Organic - digestion with 30% H_2O_2 at 95°C at 2.5 pH
Moderately reducible - extraction if hydrous iron oxides with citrate-dithionite
Residual - digestion with HF, HNO_3 and fuming HNO_3 at 95°C

Table 39

Abundances of Calcium, Iron, Manganese, and Zinc Associated with the Exchangeable Phase of Sediments Collected from the James River Artificial Habitat Development Site and a Reference Marsh in August 1976 and January 1977. Units are in meq/100 g*

	Metal	Mean	Std. Dev.	Range
Artificial Habitat	Ca	6.22	1.73	3.20 - 8.70
	Fe	0.348	0.576	BD** - 1.58
	Mn	0.492	0.346	0.004- 1.16
	Zn	0.048	0.048	0.015- 0.216
	Sum	7.11		
Reference Marsh	Ca	8.29	3.26	3.30 -14.10
	Fe	0.724	1.21	BD** - 3.98
	Mn	0.337	0.159	0.100- 0.585
	Zn	0.059	0.057	0.006- 0.175
	Sum	9.41		

* Sum of Cd, Cr, Cu, Hg, Ni, and Pb combined represented less than 0.1 meq/100 g base exchange

** BD = Below detection

Table 40

Summary Statistics for Vane Shear and Water Content Measurements at the James River Artificial Habitat Development Site and a Reference Marsh During the Entire Program from July 1975 to January 1977

Location	Depth cm	Undisturbed $g/cm^2 \pm$ S.D.	Remolded $g/cm^2 \pm$ S.D.	Water Content % ± S.D.
Artificial Habitat	4	——	——	43 ± 19
July 1975	23	57 ± 55	15 ± 11	39 ± 13
(n = 26)	53	57 ± 44	15 ± 10	41 ± 9
	83	49 ± 33	13 ± 8	46 ± 8
	114	60 ± 44	16 ± 8	45 ± 6
	140	65 ± 44	16 ± 9	43 ± 0
Reference Marsh	5	——	——	64 ± 8
August 1976	23	78 ± 64	13 ± 8	59 ± 3
(n = 3)	53	62 ± 41	10 ± 4	61 ± 15
	80	81 ± 28	11 ± 3	——
Artificial Habitat	6*	80 ± 51	10 ± 7	49 ± 11
January 1977	23	73 ± 38	15 ± 7	31 ± 12
(n = 13)	53	83 ± 37	21 ± 7	——
	83	80 ± 35	18 ± 5	46 ± 3
Reference Marsh	6*	66 ± 47	15 ± 12	76 ± 6
January 1977	23	81 ± 42	12 ± 7	60 ± 4
(n = 2)	53	115 ± 24	17 ± 6	56 ± 9
	83	103 ± 16	19 ± 9	65 ± 6

* Surface was frozen; therefore, these shear strengths are questionable

Table 41

Relative Composition of Metals Between the Dissolved Interstitial Water And Total Sediment Phases. Calculations Were for the James River Channel Cores Only

Metal	Total Phase Concentration (μg/g)	Interstitial Water Concentration (mg/l)*	Total Phase Divided by Interstitial	Interstitial as Percentage of Total (%)
Iron	40,780	57.2	713	0.14
Calcium	4,100	215.9	19	5.3
Manganese	1,100	6.94	158	0.63
Zinc	240	0.12**	2,000	0.05
Lead	62.3	0.077	809	0.12
Chromium	62†	0.034†	1,820	0.05
Copper	49.0	0.010	4,900	0.02
Nickel	33.5	0.054	620	0.16
Cadmium	1.32	0.009	147	0.68
Mercury	0.52	0.0032	162	0.62
			Mean 1,130	0.78
			Range (19 - 4,900)	(0.02 - 5.3)

* These concentrations were about two percent greater than ppm by weight because the density of water was not equal to one

** Three values greater than 1 mg/l were not included because they were suspected of being contaminated

† August 1976 data were used because only one analysis was made from July 1975 samples at the Habitat (see Table 30)

Table 42

Trends with Depth for Total Metals Analyzed in Cores Collected from the James River Artificial Habitat Development Site and a Reference Marsh in August 1976 and January 1977. Code and Numerical Values Are Constant or Insignificant Change (=,0), Increase with Depth (+, +1), and Decrease with Depth (-, -1)

Total Metal	August 1976						January 1977					
	Artificial Habitat			Reference Marsh			Artificial Habitat			Reference Marsh		
	H	I	S	H	I	S	H	I	S	H	I	S
Iron	+	=	+	=	+	+	+	=	=	+	-	-
Calcium	+	ND	ND	=	-	=	+	=	=	-	-	-
Manganese	+	=	+	=	+	-	+	=	+	=	=	-
Zinc	+	=	=	-	-	=	+	=	=	-	-	-
Lead	+	-	=	-	-	-	=	=	+	-	-	-
Chromium	=	=	=	=	=	=	+	=	=	=	=	-
Copper	+	=	=	=	=	-	+	=	=	-	-	-
Nickel	+	=	=	+	=	=	=	=	=	+	=	=
Cadmium	+	=	-	=	-	=	+	=	=	-	-	-
Mercury	+	=	=	-	=	=	-	=	+	+	-	-
Trend	9	-1	1	-2	-2	-2	6	0	3	-2	-7	-9

6 to 10 = Strong trend to increase with depth
1 to 5 = Slight trend to increase with depth
0 = No net trend
-1 to -5 = Slight trend to decrease with depth
-5 to -9 = Strong trend to decrease with depth

ND = No data

H = High marsh, I = Intertidal Marsh, S = Subtidal Marsh

Table 43

Variations in the Atomic C:N:P Ratios in Sediments at the James River Artificial Habitat Development Site and a Reference Marsh. Channel Sediments and Literature Values Are Provided for Comparison

Atomic Ratios	James River Channel	Artificial Habitat			Reference Marsh	
		July 1975	August 1976	January 1977	August 1976	January 1977
C:N:P	——*	56:9.5:1	37:2.3:1	47:1.8:1	48:5.3:1	53:3.6:1
N:P	13.8:1	9.5:1	2.3:1	1.8:1	5.3:1	3.6:1
C:N	——*	5.9:1	15.9:1	26.8:1	9:1	14.8:1

	Atomic Ratios	Comments	References
C:N:P	106:16:1	Open ocean plankton	Redfield et al. (1963)
C:N	6.6:1	Open ocean plankton	Redfield et al. (1963)
N:P	10:1 to 19:1	James River channel sediments	(from Table 3 in Volume 1)
C:N	7.3:1 to 12.4:1	Wisconsin lakes	Keeney (1972)
	9:1 to 15:1	Lake sediments	Goering (1972)
	9.3:1 to 12.6:1	Ocean sediments, Soils	Salomon (1962)
	9.5:1	Suspended organic material in Narragansett Bay	Oviatt and Nixon (1975)
	55:1 to 60:1	Dead creek bank *Spartina alterniflora* in winter	Nixon et al. (1976b)

* Channel sediments not analyzed for TOC

Table 44

Weather and Tidal Data During the August 5-7, 1976 Sampling Program, James River, Virginia

		August 5	August 6	August 7
Sunrise/Sunset (EDT)		0613/2008	0614/2007	0615/2006
Tide Gauge* (ht, ft)/(time, EDT)				
Low Tide		1.1/1745	1.3/0646 0.9/1845	1.0/0800
High Tide		3.3/1100	3.1/1200	3.7/0130
		3.9/2400		3.0/1318
NOAA Tide Tables** (ht, ft)/(time, EDT)				
Low Tide		0.2/0533	0.2/0639	0.1/0737
		0.1/1736	0.1/1840	0.0/1940
High Tide		2.1/1106	2.1/1237	2.8/0047
		2.7/2346		2.3/1313
Field Air Temperature (°C)/(time, EDT)				
Low		21.6/0945	20.4/0345	21.5/0445
High		30.3/1605	36.5/1455	23.0/0815
Field Water Temperature (°C)/(time, EDT)				
Low Tidal Channel Location†	AP	23.2/0720	21.7/0621	22.7/0750
	AB	23.2/0720	22.8/0447	22.9/0620
	RL	25.4/0840	25.0/0745	25.6/0545
	RS	25.4/0755	25.1/0845	24.8/0655
High Tidal Channel Location†	AP	28.4/1610	29.3/1200	25.2/0305††
	AB	29.6/1555	29.0/1530	25.8/0245††
	RL	28.2/1345	29.6/1345	26.7/0045††
	RS	27.7/1545	28.2/1400	26.7/0050††

(continued)

Table 44 (Concluded)

	August 5	August 6	August 7
Climatological Data‡			
Air Temperature (°C)/(time, EDT)‡‡			
Low	(15.6) 14.4/0400	(18.3) 17.8/0400	(20.6) 21.1/0400
High	(32.2) 32.2/1600	(35.0) 35.0/1400	(34.4) 32.2/1300
Average Relative Humidity (%)	66	60	71
Precipitation (inches)	0	0	0
Wind			
Average Velocity (mph)	5.3	7.1	6.0
Resultant Direction (degrees)	200	200	170
Sunshine			
Duration (min)	599	674	262
Percent of Possible Total	71	81	31

* Field tide gauge information at Belcher's Wharf was supplied by WES representative (see Figure 1 for location)

** Tidal information for Windmill Point, James River, VA

† See Figures 2 and 3 for station locations

†† Maximum temperature recorded during the sample period, which ended 0900 EDT, August 7. The daily maximum temperature would be reached in the afternoon

‡ At R.E. Byrd International Airport, Richmond, VA, approximately 37 km northwest of the Artificial Habitat Development Site

‡‡ Times are approximate, based on observations at 3-hour intervals at Byrd Airport. Air temperature (15.6) recorded in Hopewell at Va. American Water Co. were 24-hr minimum and maximum temperatures only

Table 45

Weather and Tidal Data During the January 8-10, 1977 Sampling Program, James River, Virginia

		January 8	January 9	January 10
Sunrise/Sunset (EST)		0714/1655	0713/1655	0713/1656
Tide Gauge* (ht, ft)/(time, EST)				
Low Tide		1.25/1052	0.79/1052	1.91/1208
		0.77/2322	1.64/2315	
High Tide			2.74/0452	4.05/0545
		3.18/1630	3.47/1738	3.15/1700
NOAA Tide Tables** (ht, ft)/(time, EST)				
Low Tide		-0.4/1021	-0.3/1106	-0.3/1154
		-0.4/2258	-0.4/2338	
High Tide		1.9/0356	2.0/0437	2.0/0524
		2.3/1614	2.2/1656	2.1/1742
Field Air Temperature (°C)/(time, EST)				
Low		-1.4/1750	-6.0/0730	-1.0/0700
High		5.5/1430	2.4/1230	6.5/1130
Field Water Temperature (°C)/(time, EST)				
Low Tidal Channel Location†	AP	-0.4/1935	-0.2/0015	0.4/0630
	AB	-0.2/2110	-0.1/0205	0.4/0650
	RL	-0.5/1221	0.2/0030	0.4/1000
	RS	0.0/1250	0.0/0010,2030	0.3/1000
High Tidal Channel Location†	AP	3.5/1340	3.3/1315	4.2/1245
	AB	3.4/1310	2.4/1130	4.4/1300
	RL	1.5/1530	1.0/1230	1.8/0430
	RS	1.4/1640	1.0/1200	2.0/1600

(continued)

Table 45 (Concluded)

	January 8	January 9	January 10
Climatological Data††			
Air Temperature (°C)/(time, EST)‡			
Low	-12.8/0800	-9.4/0500	-7.8/2300
High	1.7/1700	0.6/1600	6.1/1700
Average Relative Humidity (%)	62	83	81
Precipitation (inches)	0	0.32‡‡	0.51
Wind			
Average Velocity (mph)	4.6	5.0	11.8
Resultant Direction (degrees)	350	080	260
Sunshine			
Duration (min)	512	003	121
Percent of Possible Total	88	1	21

* Field tide gauge information at Belcher's Wharf was supplied by WES representative (see Figure 1 for location)

** Tidal information for Windmill Point, James River, VA

† See Figures 2 and 3 for station locations

†† At R.E. Byrd International Airport, Richmond, VA., approximately 37 km northwest of the Artificial Habitat Development Site

‡ Times are approximate, based on observations at 3-hour intervals

‡‡ Water equivalent in inches (1.7 inches of snow was recorded) with conversion by U.S. Weather Service

Table 46

Cumulative Surface Area Tidal Inundation at the James River Artificial Habitat Development Site and a Natural Reference Marsh Near Ducking Stool Point from Topographic Surveys in 1976 and 1977*

(See Figure 1 for Locations)

Tidal Height		ARTIFICIAL HABITAT						REFERENCE MARSH		REFERENCE MARSH/ ARTIFICIAL HABITAT	
		July 1975		April 1976		March-April 1977		August 1977			
(ft)	(m)	(ft^2)	(m^2)	(ft^2)	(m^2)	(ft^2)	(m^2)	(ft^2)	(m^2)	April 1976	Mar-April 1977
-1.0	-0.305							29,137	2,706.9		
0.0	0.000							123,788	11,500.3		
0.2	0.061							158,974	14,769.3		
0.4	0.122							200,628	18,639.0		
0.6	0.183							255,289	23,717.2		
0.8	0.244							357,200	33,185.1		
1.0	0.305							447,273	41,553.2		
1.2	0.366							653,166	60,681.3		
1.3	0.396					75	7.0				
1.4	0.427					450	41.8	862,075	80,089.7		1,900.0
1.5	0.457			50	4.6	1,000	92.9				
1.6	0.488			100	9.3	2,600	241.5	1,022,369	94,981.6	10,200.0	393.0
1.7	0.305			300	27.9	2,975	276.4				
1.8	0.549			500	46.5	9,500	882.6	1,154,288	107,237.3	2,300.0	121.0
1.9	0.579			1,025	95.2	26,725	2,482.8				
2.0	0.610			1,925	178.8	62,400	5,797.2	1,252,995	116,407.5	650.0	20.0
2.1	0.640			7,800	724.6	94,875	8,814.2				
2.2	0.671			22,750	2,113.6	149,550	13,893.7	1,322,552	122,869.6	58.0	8.8
2.3	0.701			51,850	4,817.0	198,200	18,413.5				
2.4	0.732			88,550	8,226.6	235,800	21,906.6	1,395,505	129,647.1	16.0	5.9
2.5	0.762	25	2.3	126,075	11,712.8	267,175	24,821.5				
2.6	0.793	100	9.3	188,675	17,528.5	292,150	27,141.7	1,448,132	134,536.4	7.7	5.0
2.7	0.823	625	58.1	236,850	22,004.2	319,750	29,705.9				
2.8	0.854	2,750	255.5	265,800	24,693.7	339,425	31,533.7	1,487,646	138,207.4	5.6	4.4
2.9	0.884	6,875	638.7	291,500	27,081.3	358,325	33,289.6				
3.0	0.915	52,450	4,872.8	319,975	29,726.8	371,625	34,525.2	1,519,451	141,163.2	4.7	4.1
3.1	0.945	147,675	13,719.5	339,975	31,584.8	383,075	35,589.0				
3.2	0.976	207,250	19,254.2	359,650	33,412.7	394,900	36,687.5	1,539,247	143,001.2	4.3	3.9
3.3	1.006	237,500	22,064.6	375,300	34,866.6	404,100	37,542.3				

(Continued)

* Surveys at Artificial Habitat in July 1975, April, 1976, and March through April 1977.

Table 46 (Concluded)

Tidal Height		ARTIFICIAL HABITAT						REFERENCE MARSH		REFERENCE MARSH/ ARTIFICIAL HABITAT	
		July 1975		April 1976		March-April 1977		August 1977			
(ft)	(m)	(ft^2)	(m^2)	(ft^2)	(m^2)	(ft^2)	(m^2)	(ft^2)	(m^2)	April 1976	Mar-April 1977
3.4	1.037	271,250	25,200.0	392,050	36,422.8	410,000	38,090.4	1,566,712	145,552.8	4.0	3.8
3.5	1.067	302,900	28,140.4	404,300	37,560.8	416,625	38,705.9				
3.6	1.098	325,325	30,223.8	413,150	38,383.0	422,075	39,212.2	1,584,308	147,187.6	3.8	3.8
3.7	1.128	344,275	31,984.3	419,450	38,968.3	426,425	39,616.3				
3.8	1.158	357,100	33,175.8	424,875	39,472.3	430,275	39,974.0	1,596,016	148,275.3	3.8	3.7
3.9	1.189	365,500	33,956.2	427,700	39,734.8	432,750	40,203.9				
4.0	1.219	377,875	35,105.9	429,525	39,904.3	434,650	40,380.5	1,604,004	149,017.5	3.7	3.7
4.1	1.250	397,825	36,959.3	431,850	40,120.3	437,300	40,626.7				
4.2	1.280	420,350	39,051.9	433,850	40,306.3	440,150	40,891.4	1,615,996**	150,131.5**	3.7	3.6
4.3	1.311	430,350	39,981.0	436,625	40,563.9	441,675	41,033.1				
4.4	1.341	437,975	40,689.4	437,675	40,661.5	442,525	41,112.1				
4.5	1.372	442,575	41,116.7	438,450	40,733.5	443,400	41,193.4				
4.6	1.402	443,625	41,214.3	439,000	40,784.6	443,750	41,225.9				
4.7	1.433	444,125	41,260.7	439,425	40,824.1						
4.8	1.463	444,525	41,297.9	439,700	40,849.6						
4.9	1.494	444,725	41,316.5	439,750	40,854.3						

** Cumulative surface area for tidal inundation at 4.2 ft. and greater

Table 48

Protocol for Compositing Hourly Water Samples Collected from the James River Artificial Habitat Development Site and Reference Marsh During the January 8-10, 1977 Sampling Period. Sample Numbers Are Listed According to the Collection Times Shown in Figures 16, 17, and 18

Site	Flood	High Slack	Ebb	Pore Water Drainage**	Low Slack	Flood	High Slack	Pre-precipitational Ebb†	Ebb	Pore Water Drainage**	Low Slack
	1*	2	3	4	5	6	7		8	9	10
Artificial Marsh											
Pipe (AP)	1,2,3	4	5,6,7,8	9,10	11	12,13,14,15	---		16,17,18,19,20	21	22
Breach (AB)	1,2,3	4	5,6,7	---	---††	14,15	---		16,17,18	---	---††
Reference Marsh											
Large Channel (RL)	1,2,3,4	5,6	7,8,9,10,11	---	12	13,14,15,16,17	18		19,20,21	---	22,23,24
Small Channel (RS)	1,2,3,4	5,6	7,8,9,10,11	---	12	13,14,15,16,17	---		18,19,20	---	21,22,23,24
	11	12	13	14	15	16	17	18	19	20	21
Artificial Marsh											
Pipe (AP)	23,24,25	26,27	28,29	30	31	32,33,34,35	37,38	---	39,40,41	42	43
Breach (AB)	23,24,25,26	27	28,29	---	---††	33,34,35,36	---	38,39,40,41	---	---	---††
Reference Marsh											
Large Channel (RL)	26,27,28	30,31	32,33,34	---	---	36,37,38,39	---	40,41,42,43	44,45,46,47,48	---	---
Small Channel (RS)	25,26,27,28	30	31,32,33,34,35	---	---	36,37,38,39	---	40,41,42	43,44,45,46,47,48	---	---
	22										
Artificial Marsh											
Pipe (AP)	45,46,47										
Breach (AB)	45,46,47										
Reference Marsh											
Large Channel (RL)	50,51,52,53										
Small Channel (RS)	49,50,51,52,53										

* Numbering system for composite samples (total of 22).

** Period of low slack tide when water was still draining from the Artificial Habitat marsh. Substantial drainage only occurred through the pipe.

† Because of rain and wind conditions, an early ebb tide occurred.

†† During low slack water the Artificial Habitat breach (site AB) was dry.

Table 47

Protocol for Compositing Hourly Water Samples Collected from the James River Artificial Habitat Development Site and Reference Marsh During August 5-7, 1976 Sampling Period. Sample Numbers Are Listed According to Collection Times Shown in Figures 13, 14, and 15

Site	Low Slack	Flood	High Slack	Ebb	Pore Water Drainage**	Low Slack	Flood	High Slack	Ebb	Pore Water Drainage**
	1*	2	3	4	5	6	7	8	9	10
Artificial Marsh										
Pipe (AP)	1	2,3	4	6,7,8,9	10,11	12,13	15,16	17	18,19,20,21	22,23
Breach (AB)	---†	2,3	4	6,7,8	---	---†	15,16	17	18,19,20,21	---
Reference Marsh										
Large Channel (RL)	---	1,2	4,5	7,8,9	---	10,11	13,14,15	16,17,18	19,20,21,22	---
Small Channel (RS)	---	1,2	4,5	7,8,9	---	10,11	13,14,15	16,17,18	19,20,21,22	---
	11	12	13	14	15	16	17	18	19	20
Artificial Marsh										
Pipe (AP)	24,25	26,27	$28,29^{\dagger\dagger}_{1}$	$29^{\dagger\dagger}_{2}$,30	33	34	35,36,37,38	39	40,41,42	43,44,45
Breach (AB)	---†	25,26,27	28	31	---	---†	36,37,38	39,40	41,42	---
Reference Marsh										
Large Channel (RL)	23,24,25	26,27	29,30	31,32,33,34	---	35,36	37,38,39	41,42,43	45,46,47,48	---
Small Channel (RS)	23,24,25	26,27	29,30	31,32,33	---	34	37,38,39	41,42,43	45,46,47,48	---
	21									
Artificial Marsh										
Pipe (AP)	---									
Breach (AB)	---†									
Reference Marsh										
Large Channel (RL)	49									
Small Channel (RS)	49									

* Numbering system for composite samples (total of 21).

** Period of low slack tide when water was still draining from the Artificial Habitat marsh. Substantial drainage only occurred through the pipe.

† During low slack water the the Artificial Habitat breach (site AB) was dry.

†† Error during shift change in the field.

Table 49

Total Water Volume During Each Flood and Ebb Tide at the James River Artificial Habitat Development Site During the Sampling Periods of August 5-7, 1976 and January 8-10, 1977. See Appendix D' for Calculations

Tidal Stage	Volume (liters) Through Breach (AB)	Volume (liters) Through Pipes (AP)
	August 1976	
First Flood	1,600,298	1,602,005
First Ebb	3,213,442	1,767,767
Second Flood	7,138,625	421,898
Second Ebb	6,133,474	6,026,950
Third Flood	3,252,689	640,192
Third Ebb	2,067,795	832,939
Fourth Flood	7,439,605	3,165,708
Fourth Ebb	2,337,695	4,875,092
Sum of Floods	19,431,217	5,829,803
Sum of Ebbs	13,752,406	13,502,748
Net Flux	5,678,811	- 7,672,945
	January 1977	
First Flood	7,029,657	1,228,596
First Ebb	5,143,276	3,496,855
Second Flood	3,488,037	350,707
Second Ebb	3,367,415	1,232,623
Third Flood	8,972,507	1,908,549
Third Ebb	7,342,947	4,282,389
Fourth Flood	13,631,845	4,548,451
Fourth Ebb	14,265,293	4,491,404
Sum of Floods	33,122,046	8,036,303
Sum of Ebbs	30,118,931	13,503,271
Net Flux	3,003,115	- 5,466,968

Table 50

Total Water Volume During Each Flood and Ebb Tide at Ducking Stool Point Reference Marsh, James River, Virginia, During the Sampling Periods of August 5-7, 1976 and January 8-10, 1977. See Appendix D' for Calculations

Tidal Stage	Volume (liters) Through Large Channel (RL)	Volume (liters) Through Small Channel (RS)
	August 1976	
First Flood	19,579,456	10,094,617
First Ebb	29,581,270	14,110,384
Second Flood	41,275,235	21,447,922
Second Ebb	48,528,085	24,247,421
Third Flood	21,914,393	11,160,048
Third Ebb	37,188,995	14,663,791
Fourth Flood	40,472,979	22,522,891
Fourth Ebb	37,811,902	17,416,471
Sum of Floods	123,242,063	65,225,478
Sum of Ebbs	153,110,252	70,438,067
Net Flux	- 29,868,189	- 5,212,589
	January 1977	
First Flood	33,905,741	17,590,826
First Ebb	42,538,107	18,957,527
Second Flood	37,441,388	18,167,365
Second Ebb	28,238,486	13,927,078
Third Flood	36,468,915	23,991,574
Third Ebb	37,858,734	22,492,856
Fourth Flood	44,765,052	25,704,423
Fourth Ebb	51,051,265	29,811,879
Sum of Floods	152,581,096	85,454,188
Sum of Ebbs	159,686,592	85,189,340
Net Flux	- 7,105,496	264,848

Table 51

Comparisons of Mean Water Quality Parameter Values for August 1970

(Summer) and January 1977 (Winter) at the James River

Artificial Habitat Development Site and the

Reference Marsh

Parameter	Units	Development Site Summer		Development Site Winter	Reference Marsh Summer		Reference Marsh Winter
Conductivity	mmho/cm	0.175	=	0.179	0.165	>	0.106
Water temperature	°C	26.0	>	1.1	26.7	>	0.7
pH		7.18	≤	7.40	7.32	<	8.00
Dissolved oxygen	mg/ℓ	5.71	<	11.44	6.94	<	12.29
Oxygen saturation	°/ₒ	53	<	82	86	=	87
Alkalinity	meq/ℓ	--		0.49	--		0.39
Suspended solids*	mg/ℓ	86	≥	54	25	=	27
Turbidity	FTU	35	≥	22	16	≥	11
Dissolved orthophosphate	mg/ℓ	0.082	>	0.045	0.041	=	0.033
Dissolved total phosphorus	mg/ℓ	0.092	≤	0.114	0.084	≤	0.099
Total phosphorus	mg/ℓ	0.235	=	0.234	0.155	<	0.181
Dissolved ammonium	mg/ℓ	0.47	=	0.47	0.47	=	0.46
Dissolved $NO_3 + NO_2$	mg/ℓ	0.619	<	1.95	0.524	<	1.61
Dissolved total nitrogen	mg/ℓ	3.48	>	2.60	1.76	<	2.53
Total Kjeldahl nitrogen	mg/ℓ	5.25	>	3.07	4.23	>	3.29
Fo/Fa ratio		1.71	>	1.44	1.75	>	1.52
Chlorophyll	μg/ℓ	10.24	>	1.09	13.88	>	0.81
Phaeophytin	μg/ℓ	4.36	>	1.67	5.23	>	0.78
Dissolved volatile organic C	mg/ℓ	2.6	=	2.1	1.4	=	1.3
Dissolved total organic C	mg/ℓ	9.8	=	9.2	8.8	=	9.1
Particulate organic carbon	mg/ℓ	--		2.79	--		1.47
Dissolved calcium	mg/ℓ	16.3	>	13.5	13.7	>	11.6
Dissolved iron	mg/ℓ	0.489	>	0.281	0.269	=	0.299
Dissolved manganese	mg/ℓ	0.184	>	0.061	0.046	>	0.029
Dissolved mercury	μg/ℓ	0.61	>	0.31	0.61	>	0.28
Dissolved zinc	mg/ℓ	0.088	≥	0.067	0.078	≥	0.048

Note: > indicates greater than; = indicates equal to; < indicates less than. *Differences are not necessarily statistically significant.*

* At the pipe of the experimental site summer values > winter values, while at the breach of the experimental site summer values ≥ winter values.

Table 52

Comparisons of Water Quality Parameter Values for the James River Artificial Habitat Development Site and the Reference Marsh During August 1976 (Summer) and January 1977 (Winter)

		Summer			Winter		
Parameter	Units	Development Site		Reference Marsh	Development Site		Reference Marsh
Conductivity*	mmho/cm	0.175	≥	0.165	0.179	>	0.106
Water temperature	°C	26.0	=	26.7	1.1*	≥	0.7*
pH*		7.18	<	7.32	7.40	<	8.00
Dissolved oxygen*	mg/ℓ	5.71	<	6.94	11.44	<	12.29
Oxygen saturation*	°/₀	53	<	86	82	≤	87
Alkalinity	meq/ℓ	--		--	0.49*	>	0.39*
Suspended solids	mg/ℓ	86*	>	25*	54	>	27
Turbidity*	FTU	35	>	16	22	>	11
Dissolved orthophosphate *	mg/ℓ	0.082	>	0.041	0.045	≥	0.033
Dissolved total phosphorus	mg/ℓ	0.092	≥	0.084	0.114*	≥	0.099*
Total phosphorus*	mg/ℓ	0.235	>	0.155	0.234	>	0.181
Dissolved ammonium	mg/ℓ	0.47	=	0.47	0.47	=	0.46
Dissolved NO_3 + NO_2*	mg/ℓ	0.619	>	0.524	1.95	>	1.61
Dissolved total nitrogen	mg/ℓ	3.48*	>	1.76*	2.60	=	2.53
Total Kjeldahl nitrogen	mg/ℓ	5.25	≥	4.23	3.07	=	3.29
Fo/Fa ratio		1.71	=	1.75	1.44*	<	1.52*
Chlorophyll	μg/ℓ	10.24*	<	13.88*	1.09	≥	0.81
Phaeophytin*	μg/ℓ	4.36	<	5.23	1.67	>	0.78
Dissolved volatile organic C*	mg/ℓ	2.6	>	1.4	2.1	>	1.3
Dissolved total organic C	mg/ℓ	9.8	≥	8.8	9.2	=	9.1
Particulate organic carbon	mg/ℓ	--		--	2.79	≥	1.47
Dissolved calcium*	mg/ℓ	16.3	>	13.7	13.5	>	11.6
Dissolved iron*	mg/ℓ	0.489	>	0.269	0.281	=	0.299
Dissolved manganese*	mg/ℓ	0.184	>	0.046	0.061	>	0.029
Dissolved mercury	μg/ℓ	0.61	=	0.61	0.31	=	0.28
Dissolved zinc	mg/ℓ	0.088	≥	0.078	0.067*	≥	0.048*

Note: > indicates greater than; = indicates equal to; < indicates less than. Differences are not necessarily statistically significant.

* Parameter values were significantly different when comparing flood tide values and ebb tide values. Slack tidal values were not tested.

Table 53

Parameters That Tested Significantly Different by ANOVA Between the James River Artificial Habitat Development Site and a Reference Marsh. These Were Analyzed for Ebb and Flood Tides at Two Channels for Each Marsh During Four Tidal Cycles (Approximately 48 to 54 hrs) in August 1976 and Again in January 1977. Categories Were Very, Very Significant (VVS, $F_{0.001}$), Very Significant (VS, $F_{0.01}$) and Significant (S, $F_{0.05}$). Codes in Brackets List the Marsh (A=Artificial Habitat, R=Reference Marsh) Which Had the Higher Values for the Specific Parameter

MARSH FACTOR					
AUGUST 1976			JANUARY 1977		
VVS	VS	S	VVS	VS	S
(A) Suspended Solids	(R) Chlorophyll		(A) Water Temperature	(A) Alkalinity**	
(A) Turbidity*	(R) Phaeophytin*	(A) Conductivity*	(A) Conductivity*	(A) Phaeophytin*	
(R) Dissolved Oxygen*		(R) pH*,+	(A) Turbidity*		
(R) Oxygen Saturation*		(A) Volatile Dissolved Organic Carbon *+	(R) pH*		
(A) Dissolved Orthophosphate*		(A) Total Phosphorus*	(R) Dissolved Oxygen*		
(A) Total Dissolved Nitrogen			(R) Oxygen Saturation*		
(A) Nitrate + Nitrite*			(R) Fo/Fa Ratio		
(A) Dissolved Calcium*			(A) Volatile Dissolved Organic Carbon*		
(A) Dissolved Iron*			(A) Total Phosphorus*		
(A) Dissolved Manganese*			(A) Total Dissolved Phosphorus		
			(A) Dissolved Orthophosphate*		
			(A) Nitrate + Nitrite*		
			(A) Dissolved Calcium*		
			(R) Dissolved Iron*		
			(A) Dissolved Manganese*		
			(A) Dissolved Zinc		

* Parameter at some level of significance for both seasons

** Data excluded from the ANOVA for August 1976

+ Slightly less than $F_{0.05}$ (see Appendix E')

Table 54

Comparisons of Mean Water Quality Parameter Values for Separate Sampling Locations at the James River Artificial Habitat Development Site and the Reference Marsh During August 1976 (Summer) and January 1977 (Winter)

		Summer						Winter					
		Development Site			Reference Marsh			Development Site			Reference Marsh		
Parameter	Units	Pipe		Breach	Large		Small	Pipe		Breach	Large		Small
Conductivity	mmho/cm	0.178	>	0.171	0.164	=	0.167	0.170	<	0.192	0.104	=	0.109
Water temperature	°C	25.8	=	26.2	26.8	=	26.5	1.1	=	1.2	0.7	=	0.6
pH		7.11	<	7.28	7.34	=	7.30	7.41	=	7.39	8.00	=	7.99
Dissolved oxygen	mg/ℓ	5.48	<	6.00	7.10	>	6.77	11.40	=	11.50	12.25	=	12.34
Oxygen saturation	°/₀	67	<	73	88	≥	83	82	=	83	87	=	87
Alkalinity	meq/ℓ	--		--	--		--	0.49	=	0.49	0.39	=	0.40
Suspended solids	mg/ℓ	117	>	37	26	=	23	69	>	31	24	=	29
Turbidity	FTU	44	>	23	16	=	17	25	≥	17	11	=	12
Dissolved orthophosphate	mg/ℓ	0.080	>	0.051	0.037	≤	0.043	0.048	=	0.040	0.033	=	0.035
Dissolved total phosphorus	mg/ℓ	0.103	>	0.080	0.059	<	0.109	0.104	<	0.123	0.104	≥	0.095
Total phosphorus	mg/ℓ	0.251	>	0.214	0.147	≤	0.162	0.221	<	0.257	0.184	=	0.178
Dissolved ammonium	mg/ℓ	0.46	≤	0.51	0.48	=	0.46	0.47	=	0.45	0.48	≥	0.43
Dissolved NO_3 + NO_2	mg/ℓ	0.537	<	0.705	0.463	<	0.617	2.08	>	1.81	1.66	≥	1.55
Dissolved total nitrogen	mg/ℓ	3.30	<	3.68	2.19	>	1.33	2.74	>	2.34	2.66	≥	2.40
Total Kjeldahl nitrogen	mg/ℓ	5.83	>	4.45	4.70	>	3.76	3.69	>	2.86	3.54	≥	3.30
Fo/Fa ratio		1.68	<	1.75	1.75	=	1.75	1.42	=	1.46	1.52	=	1.52
Chlorophyll	µg/ℓ	9.87	<	10.78	14.08	>	13.68	1.21	>	0.92	0.77	≤	0.86
Phaeophytin	µg/ℓ	4.85	>	3.64	5.54	>	4.94	1.96	>	1.22	0.74	≤	0.83
Dissolved volatile organic C	mg/ℓ	3.2	>	1.7	1.3	=	1.6	2.2	=	2.0	1.0	≤	1.5
Dissolved total organic C	mg/ℓ	10.5	>	8.9	8.9	=	8.7	9.6	>	8.6	8.0	≤	10.2
Particulate organic carbon	mg/ℓ	--		--	--		--	3.49	>	1.75	1.33	≤	1.62
Dissolved calcium	mg/ℓ	17.0	>	15.2	14.1	>	13.2	13.4	=	13.6	11.5	=	11.9
Dissolved iron	mg/ℓ	0.625	>	0.296	0.276	=	0.261	0.288	=	0.271	0.289	≤	0.309
Dissolved manganese	mg/ℓ	0.218	>	0.136	0.044	=	0.049	0.078	>	0.037	0.029	=	0.030
Dissolved mercury	µg/ℓ	0.64	≥	0.55	0.55	=	0.66	0.28	=	0.39	0.28	=	0.26
Dissolved zinc	mg/ℓ	0.071	<	0.112	0.079	=	0.078	0.072	≥	0.060	0.062	>	0.033

Note: > indicates greater than; = indicates equal to; < indicates less than. Differences are not necessarily statistically significant.

Table 55

Parameters That Tested Significantly Different by ANOVA at the James River Artificial Habitat Development Site and a Reference Marsh for Tides (Ebb or Flood), Stations (Two Tidal Channels at Each Marsh), Day or Night, Blocks (First Day or Second Day), and Replicates (Alpha or Beta). Categories Are Very, Very Significant (VVS, $F_{0.001}$), Very Significant (VS, $F_{0.01}$) and Significant (S, $F_{0.05}$). Codes in Brackets List Tides or Stations which Had Higher Values for the Specified Parameter

AUGUST 1976			JANUARY 1977		
VVS	VS	S	VVS	VS	SS
		TIDAL FACTOR			
(F) pH	(F) Dissolved Oxygen*	(F) Chlorophyll	(F) Water Temperature	(F) Phaeophytin	(F) Dissolved Oxygen*
(E) Dissolved Orthophosphate	(F) Oxygen Saturation*	(E) Volatile Dissolved Organic Carbon	(F) Oxygen Saturation*		(?) Dissolved Ammonium**
	(E) Dissolved Iron	(E) Dissolved Manganese*	(E) Dissolved Manganese*		
		STATION FACTOR			
	(P,S) Dissolved Total Phosphorus*	(P,L) Dissolved Calcium*	(B,?) Total Phosphorus	(P,L) Total Kjeldahl Nitrogen	(P,?) Turbidity (?)**
	(P,?) Dissolved Iron	(B,?) Dissolved Zinc*	(B,L) Dissolved Total Phosphorus*	(P,L) Dissolved Nitrate Plus Nitrite	(?,?) Dissolved Ammonium
			(P,L) Dissolved Total Nitrogen	(B,S) Dissolved Calcium*	(?,S) Dissolved Mercury
			(P,?) Dissolved Manganese		
			(P,L) Dissolved Zinc*		
		DAY/NIGHT FACTOR			
Water Temperature*	pH	Dissolved Oxygen	Water Temperature*	Total Kjeldahl Nitrogen	Turbidity
		Oxygen Saturation	Alkalinity†		Dissolved Ammonium
		Fo/Fa Ratio	Total Phosphorus		
		Phaeophytin	Total Dissolved Phosphorus		
		Dissolved Manganese			
		BLOCKS (B) AND REPLICATES (R) FACTOR			
Water Temperature (B)	Dissolved Total Phosphorus (R)	Dissolved Mercury (B)		Dissolved Orthophosphate (R)	
				Dissolved Calcium (R)	
				Dissolved Zinc (R)	

Higher values listed as F = Flood, E = Ebb, P = Habitat Pipe, B = Habitat Breach, L = Reference Marsh Large Channel, S = Reference Marsh Small Channel, and ? = Uncertain

* Parameter at some level of significance for both seasons

** Slightly less than $F_{0.05}$ (see Appendix E')

† Data excluded from the ANOVA for August 1976

Table 56

Comparisons of Mean Water Quality Parameter Values for Ebb and Flood Tidal Periods at the James River Artificial Habitat Development Site Pipe During August 1976 (Summer) and January 1977 (Winter)

Parameter	Units	Summer Flood		Summer Ebb	Winter Flood		Winter Ebb
Conductivity*	mmho/cm	0.169	<	0.184	0.151	<	0.181
pH		7.29	>	7.00	7.47	=	7.38
Dissolved oxygen	mg/ℓ	6.24	>	4.87	11.48	=	11.27
Oxygen saturation	°/o	77	>	59	83	=	80
Alkalinity	meq/ℓ	--		--	0.48	=	0.51
Suspended solids	mg/ℓ	55	<	145	53	=	53
Turbidity	FTU	31	<	50	24	=	23
Dissolved orthophosphate	mg/ℓ	0.067	<	0.089	0.054	=	0.043
Dissolved total phosphorus	mg/ℓ	0.087	<	0.113	0.096	=	0.108
Total phosphorus*	mg/ℓ	0.176	<	0.277	0.204	⩽	0.233
Dissolved ammonium*	mg/ℓ	0.43	⩽	0.48	0.44	⩽	0.50
Dissolved NO_3 + NO_2	mg/ℓ	0.674	>	0.435	2.03	=	2.11
Dissolved total nitrogen*	mg/ℓ	2.83	<	3.61	2.60	⩽	2.83
Total Kjeldahl nitrogen	mg/ℓ	6.01	⩾	5.74	3.40	⩽	3.88
Fo/Fa ratio		1.69	=	1.67	1.44	=	1.40
Chlorophyll	μg/ℓ	10.25	⩾	9.62	1.11	=	1.01
Phaeophytin*	μg/ℓ	4.09	<	5.22	1.62	<	2.62
Dissolved volatile organic C*	mg/ℓ	2.4	<	3.8	1.8	<	2.7
Dissolved total organic C	mg/ℓ	9.4	<	11.1	9.5	=	9.5
Particulate organic carbon	mg/ℓ	--		--	2.78	=	2.70
Dissolved calcium	mg/ℓ	15.5	<	17.9	13.8	=	13.2
Dissolved iron*	mg/ℓ	0.776	⩽	0.795	0.255	<	0.332
Dissolved manganese*	mg/ℓ	0.127	<	0.273	0.045	<	0.113
Dissolved mercury	μg/ℓ	0.74	⩾	0.58	0.26	=	0.31
Dissolved zinc	mg/ℓ	0.067	=	0.074	0.074	=	0.070

Note: > indicates greater than; = indicates equal to; < indicates less than. Differences are not necessarily statistically significant.

* Ebb tidal cycle (porewater drainage + low slack + ebb) statistical mean greater than flood cycle (flood + high slack) statistical mean concentrations for both August and January sampling periods.

Table 57

Cation Exchange Capacity (NaEC) of Suspended Sediments Collected at the Tidal Channels of the James River Artificial Habitat Development Site and a Reference Marsh, August 1976 and January 1977

August 1976			January 1977		
Location	Tide	CEC (meq/100 g)	Location	Tide	CEC (meq/100 g)
Habitat Site			Habitat Site		
Habitat Pipe and	Ebb	39	Pipe	Ebb	114
Breach Combined	Ebb	63	Pipe	Flood	164
			Breach	Ebb	97
			Breach	Flood	116
Mean ± Std. Dev.		51 ± 17			123 ± 29
Reference Marsh			Reference Marsh		
Reference Large and Small Channels Combined	Ebb	284	Large Channel	Ebb	151
	Flood	96	Large Channel	Flood	129
			Small Channel	Ebb	141
			Small Channel	Flood	106
Mean ± Std. Dev.		190 ± 133			132 ± 19

Table 58

Net Chemical Exports Through All Sampling Locations at the James River Artificial Habitat Development Site and Reference Marsh During August 1976 (Summer) and January 1977 (Winter)

Development Site Parameter	Export, kg	Reference Marsh Parameter	Export, kg
	August 1976		
Dissolved volatile organic carbon	61.2 ± 15.2*	Total Kjeldahl nitrogen	292 ± 120*
Dissolved orthophosphate	0.56 ± 0.15*	Dissolved zinc	3.93 ± 1.67*
Particulate copper	0.124 ± 0.015*	Dissolved manganese	3.47 ± 0.91*
Dissolved orthophospate (serial at AB)	0.10 ± 0.09*	Dissolved orthophosphate	1.60 ± 0.68*
		Dissolved orthophosphate†	0.38 ± 0.30*
		Particulate nickel	0.743 ± 0.097*
		Particulate copper	0.336 ± 0.056*
		Dissolved mercury	0.035 ± 0.017*
Dissolved total nitrogen	34.63 ± 8.68**	Dissolved volatile organic carbon	142 ± 104**
Dissolved manganese	0.99 ± 0.67**	Dissolved nitrate plus nitrite‡	17.2 ± 10.7**
Dissolved total phosphorus	0.30 ± 0.16**	Dissolved iron	7.84 ± 4.86**
		Dissolved total phosphorus	1.89 ± 1.37**
		Particulate lead	0.425 ± 0.086**
		Particulate cadmium	0.030 ± 0.010**
Particulate iron	13.76 ± 17.54††	Dissolved total organic carbon	276 ± 389††
Dissolved nitrate plus nitrite‡	1.21 ± 1.83††	Dissolved oxygen	70 ± 109††
	January 1977		
Dissolved total organic carbon	60.5 ± 44.5*	None for first category*	
Dissolved volatile organic carbon	23.7 ± 9.9*		
Alkalinity‡‡	3.91 ± 2.71		
Particulate cadmium§	0.0009 ± 0.0003*		
Dissolved mercury	0.0025 ± 0.0081**	Dissolved total organic carbon	514 ± 211**
		Particulate cadmium	0.007 ± 0.004**
Dissolved manganese	0.24 ± 0.31 ††	Total Kjeldahl nitrogen	29.2 ± 108††
Dissolved total phosphorus	0.23 ± 0.25 ††	Dissolved orthophosphate	0.33 ± 0.55††

Note: Net export values are volume normalized to allow direct ebb to flood comparisons.
* Volume normalized net mass transport at both channels were greater than the error terms, expressed at the ± one sigma level.
** Volume normalized net mass transport at one channel only was greater than the error terms, expressed at the ± one sigma level.
† Analysis of serial data for small reference channel only; the large reference channel was not considered in calculations of total net mass transport because serial data for the large reference channel was not available.
†† Error terms at the ± one sigma level were greater than the volume normalized net mass transport at both channels.
‡ Composite data for the experimental pipe at large reference channel plus serial data for the experimental breach or small reference channel.
‡‡ Data for winter period only were available; values are in equivalents rather than kg as with the other parameters.
§ Significant net export calculated for the breach only. Data for the pipe were below detection limit.

Table 59

Net Chemical Imports Through All Sampling Locations at the James River Artificial Habitat Development Site and Reference Marsh During August 1976 (Summer) and January 1977 (Winter)

Development Site		Reference Marsh	
Parameters	Import, kg	Parameters	Import, kg
	August 1976		
Dissolved oxygen	55 ± 8.3*	Dissolved total nitrogen	71.7 ± 80.6**
		Dissolved ammonium†	13.2 ± 12.1**
		Particulate zinc	0.49 ± 0.18**
Particulate manganese	0.73 ± 0.45**	Dissolved ammonium†	11.0 ± 13.2†
Total phosphorus	0.59 ± 0.85**	Total phosphorus	2.56 ± 2.48†
Dissolved zinc	0.41 ± 0.28**	Chlorophyll	0.73 ± 252†
Dissolved ammonium	0.34 ± 1.45†		
Chlorophyll	0.09 ± 23.6†		
	January 1977		
Particulate manganese	0.601 ± 0.150*	Dissolved volatile organic carbon	87 ± 24*
		Particulate manganese	3.25 ± 0.66*
Suspended solids	175 ± 213**	Dissolved calcium	148 ± 92**
Dissolved total nitrogen	9.56 ± 5.92**	Particulate iron	82 ± 31**
Dissolved orthophosphate	0.14 ± 0.13**	Particulate calcium	9.05 ± 2.62**
		Alkalinity††	6.69 ± 7.47**
		Particulate lead	0.157 ± 0.068**
		Particulate copper‡	0.045 ± 0.014**
Particulate carbon††	8.43 ± 13.47†	Dissolved oxygen	77 ± 79†
		Chlorophyll	0.02 ± 13†
		Phaeophytin	0.04 ± 19†
Dissolved zinc	0.085 ± 0.311†		
Phaeophytin	0.006 ± 8.35†		

Note: Net import values are volume normalized to allow direct flood to ebb comparisons.
* Volume normalized net mass transport at both channels was greater than the error terms, expressed at the ± one sigma level.
** Volume normalized net mass transport at both channels was greater than the error terms, expressed at the ± one sigma level. Dissolved ammonium concentrations after H_2SO_4 storage.
† Error terms at the ± one sigma level were greater than the volume normalized net mass transport of both channels. Dissolved ammonium concentrations after $HClO_4$ storage.
†† Alkalinity and particulate carbon data were available only for the winter sampling period; values for alkalinity are in equivalents rather than kg as with the other parameters.
‡ Significant net import calculated for the large reference channel only. Data not available for the small reference channel.

Table 60

Parameters Calculated as Net Exports at one Sampling Location and Net Imports at the Other Sampling Location in both the James River Artificial Habitat Development Site and Reference Marsh during August 1976 (Summer) and January 1977 (Winter)

Development Site

Parameters**	Location	Export, kg	Location	Import, kg
August 1976				
Suspended solids	Breach	119 ± 133	Pipe	190 ± 294
Dissolved total organic carbon	Pipe	55.6 ± 22.9*	Breach	0.33 ± 67.7
Dissolved calcium	Pipe	16.3 ± 9.0*	Breach	2.98 ± 13.5
Total Kjeldahl nitrogen	Breach	4.44 ± 20.8	Pipe	20.7 ± 19.3*
Dissolved iron*	Breach	2.64 ± 0.84*	Pipe	2.41 ± 1.29*
Dissolved nitrate plus nitrite	Pipe	0.88 ± 0.89	Breach	0.33 ± 1.61
Dissolved ammonium††	Breach	0.73 ± 1.03	Pipe	0.14 ± 0.53
Particulate calcium	Pipe	0.39 ± 0.92	Breach	0.09 ± 0.68
Particulate nickel*	Pipe	0.035 ± 0.018*	Breach	0.030 ± 0.014*
Particulate lead	Pipe	0.016 ± 0.023	Breach	0.006 ± 0.012
Particulate zinc	Pipe	0.015 ± 0.074	Breach	0.061 ± 0.050*
Phaeophytin	Pipe	0.003 ± 5.96	Breach	0.02 ± 10.1
Particulate cadmium*	Pipe	0.0018 ± 0.0016*	Breach	0.0108 ± 0.0025*
Dissolved mercury	Breach	0.0008 ± 0.0019	Pipe	0.0041 ± 0.0006*
January 1977				
Dissolved oxygen	Breach	9.3 ± 18.3	Pipe	10.5 ± 5.8*
Particulate iron	Breach	2.63 ± 4.99	Pipe	17.4 ± 4.5*
Dissolved ammonium	Pipe	1.54 ± 1.18*	Breach	0.59 ± 1.06
Dissolved calcium	Pipe	1.39 ± 8.11	Breach	10.5 ± 22.1
Total Kjeldahl nitrogen	Pipe	1.28 ± 6.14	Breach	16.7 ± 10.3*
Dissolved nitrate plus nitrite	Pipe	1.22 ± 3.54	Breach	2.59 ± 5.78
Dissolved iron	Breach	0.96 ± 1.87	Pipe	0.10 ± 0.54
Particulate calcium	Breach	0.38 ± 0.52	Pipe	1.86 ± 0.47*
Total phosphorus	Pipe	0.34 ± 0.22*	Breach	0.32 ± 0.48
Particulate nickel*	Breach	0.020 ± 0.009*	Pipe	0.023 ± 0.007*
Particulate zinc	Breach	0.019 ± 0.032	Pipe	0.153 ± 0.034*
Particulate copper*	Breach	0.017 ± 0.006*	Pipe	0.044 ± 0.008*
Particulate lead	Breach	0.007 ± 0.104	Pipe	0.030 ± 0.009*
Chlorophyll	Pipe	0.001 ± 2.14	Breach	0.001 ± 3.95

Reference Marsh

Parameters**	Tidal Channel	Export, kg	Tidal Channel	Import, kg
August 1976				
Suspended solids	Small	198 ± 282	Large	56 ± 692
Dissolved calcium	Large	116 ± 98*	Small	14.5 ± 48.2
Particulate iron	Small	27.8 ± 11.7*	Large	3.5 ± 32
Dissolved nitrate plus nitrite†	Large	10.1 ± 7.4*	Small	0.36 ± 4.35
Particulate calcium	Small	1.52 ± 1.05*	Large	0.44 ± 3.20
Particulate manganese	Small	0.45 ± 0.57	Large	0.98 ± 1.68
Phaeophytin	Small	0.06 ± 67	Large	0.27 ± 107
January 1977				
Dissolved total nitrogen*	Large	131 ± 48*	Small	16.4 ± 15.3*
Suspended solids	Small	72 ± 719	Large	231 ± 646
Dissolved ammonium*	Large	33 ± 12*	Small	14 ± 4.7*
Particulate carbon‡	Small	7.75 ± 39.98	Large	13.73 ± 33.68
Dissolved nitrate plus nitrite	Large	7.50 ± 32.9	Small	5.49 ± 10.6
Dissolved iron	Small	0.90 ± 2.40	Large	2.47 ± 4.18
Dissolved total phosphorus	Small	0.82 ± 0.63*	Large	0.16 ± 0.97
Total phosphorus	Small	0.72 ± 1.29	Large	1.78 ± 2.94
Dissolved zinc*	Small	0.68 ± 0.37*	Large	1.32 ± 0.98*
Particulate zinc*	Small	0.429 ± 0.176*	Large	0.448 ± 0.130*
Dissolved manganese	Small	0.30 ± 0.16*	Large	0.09 ± 0.34
Particulate nickel*	Small	0.196 ± 0.081*	Large	0.074 ± 0.048*
Dissolved mercury	Large	0.001 ± 0.003	Small	0.006 ± 0.004*

Note: Net imports and export values normalized to allow direct flood to ebb comparisons.
* Error terms listed at the ± one sigma level. Parameter listing indicates significant volume normalized export and import terms, which are denoted in their respective columns.
** Ranked according to decreasing net export.
† Transport calculated for composited samples only; see Table 58 for other calculations.
†† Storage for six weeks (-20 C) with perchloric acid.
‡ Particulate carbon data were available only for the winter sampling period.

Table 61

Net Transport of Dissolved and Particulate Metals at the James River Artificial Habitat Development Site and Reference Marsh

	Development Site				Reference Marsh			
	Export, kg		Import, kg		Export, kg		Import, kg	
Parameter	Particulate	Dissolved	Particulate	Dissolved	Particulate	Dissolved	Particulate	Dissolved
				August 1976				
Cadmium		--	0.009	--	0.030	--		--
Calcium	0.30	13.3*			1.08	102*		
Copper	0.124	--		--	0.336	--		--
Iron	13.76*	0.23			24.3*	7.84		
Lead	0.010	--		--	0.425	--		--
Manganese		0.99	0.73			3.47*	0.53	
Mercury	--		--	0.003	--	0.035	--	
Nickel	0.005	--		--	0.743	--		--
Zinc			0.046	0.41*		3.93*	0.49	
				January 1977				
Cadium	0.0009	--		--	0.007	--		--
Calcium			1.48	9.11*			9.05	148*
Copper		--	0.027	--		--	0.045	--
Iron		0.86	14.8*				82*	1.57
Lead		--	0.023	--		--	0.16	--
Manganese		0.24	0.60			0.21	3.25*	
Mercury	--	0.0025	--		--		--	0.005
Nickel		--	0.003	--	0.122	--		--
Zinc			0.134	0.085			0.019	0.64*

Note: 1. Net import and export values are volume normalized to allow direct flood to ebb comparisons.
2. See Tables 58-60 for standard error values for all listed mean values.
3. -- Indicates that no transport was calculated due mostly to sample levels below analytical detection limits (Table 5 in Volume I).
* Denotes phase for calcium, iron, manganese, and zinc which has greater net mass transport.

Table 62

Net Mass Transport of Suspended Solids, Dissolved Oxygen, Nutrients, Carbon, Chlorophyll, and Phaeophytin at the James River Site and a Reference Marsh

Parameter	Development Site		Reference Marsh	
	Export, kg	Import, kg	Export, kg	Import, kg
August 1976				
Suspended solids		71	142	
Dissolved oxygen		55	70	
Dissolved orthophosphate	0.56		1.60	
Dissolved total phosphorus	0.30		1.89	
Total phosphorus		0.59		2.56
Dissolved ammonium		0.34		13.2
Dissolved nitrate plus nitrite	0.55		17.2	
Dissolved total nitrogen	34.6			71.7
Total Kjeldahl nitrogen		16.3	292	
Dissolved total organic carbon	55.3		276	
Dissolved volatile organic carbon	61.2		142	
Chlorophyll		0.09		0.73
Phaeophytin		0.02		0.21
January 1977				
Suspended solids		175		159
Dissolved oxygen		1.2		77
Dissolved orthophosphate		0.14	0.33	
Dissolved total phosphorus	0.23		0.66	
Total phosphorus	0.02			1.06
Dissolved ammonium	0.95		19	
Dissolved nitrate plus nitrite		1.37	2.0	
Dissolved total nitrogen		9.56	115	
Total Kjeldahl nitrogen		15.4	29.2	
Dissolved total organic carbon	60.5		514	
Dissolved volatile organic carbon	23.7			87
Particulate organic carbon*		8.43		5.98
Chlorophyll	0.00			0.02
Phaeophytin		0.006		0.04

Note: 1. Net import and export values are volume normalized to allow direct flood to ebb comparisons.

2. See Tables 58-60 for standard error values for all listed mean values.

* Calculated for winter sampling period only.

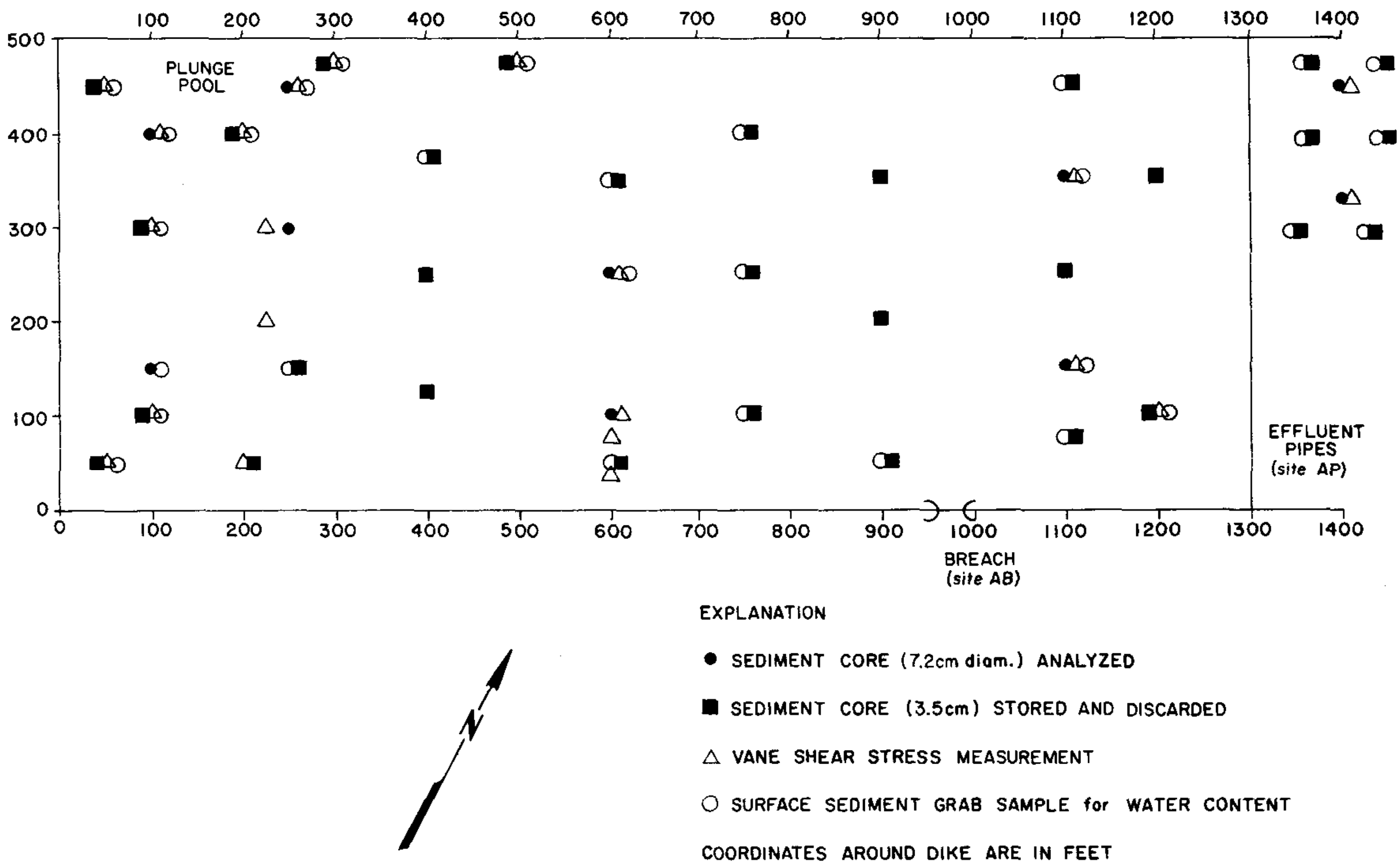

Figure 7. Locations of sampling sites at the James River Artificial Habitat Development Site in July 1975.

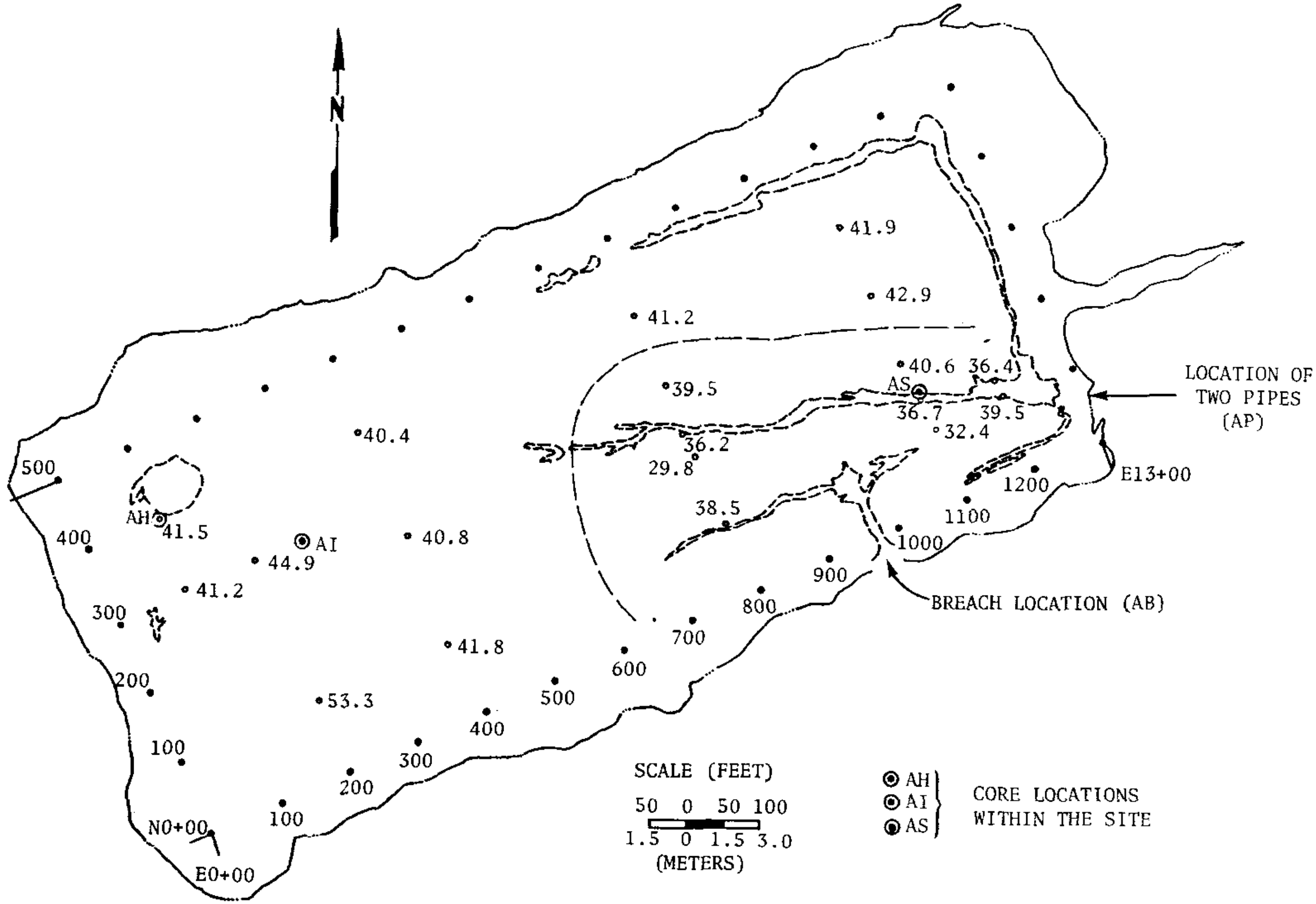

Figure 8. Cation exchange capacity (NaEC) of the surface sediments at the James River Artificial Habitat Development Site in July 1976. The dashed line separates the area closest to the tidal channel in the southeast corner of the marsh near the outlet pipes and breach.

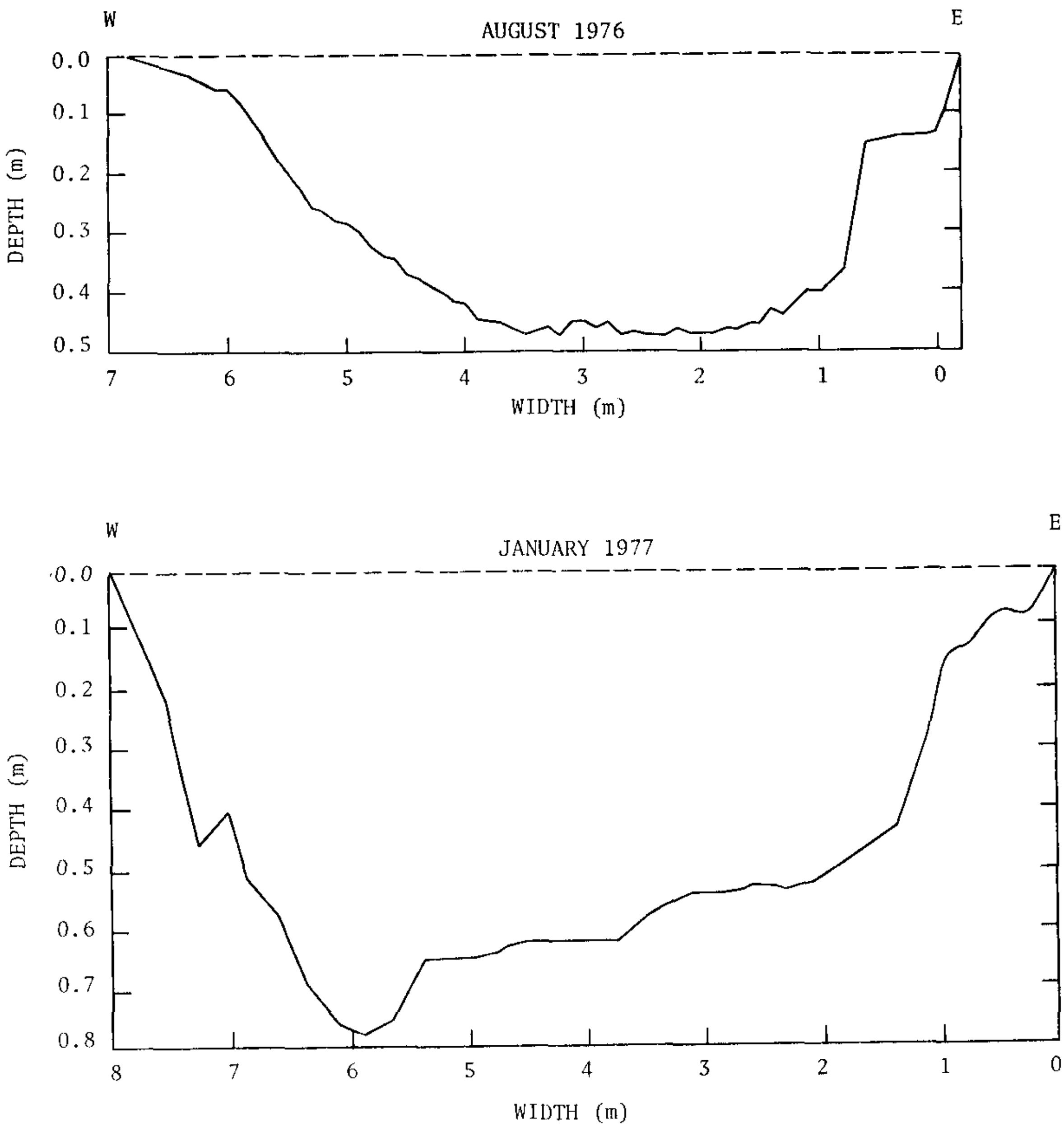

Figure 9. Cross sections of the breach (AB) at the James River Artificial Habitat Development Site, Virginia, during August 1976 and January 1977.

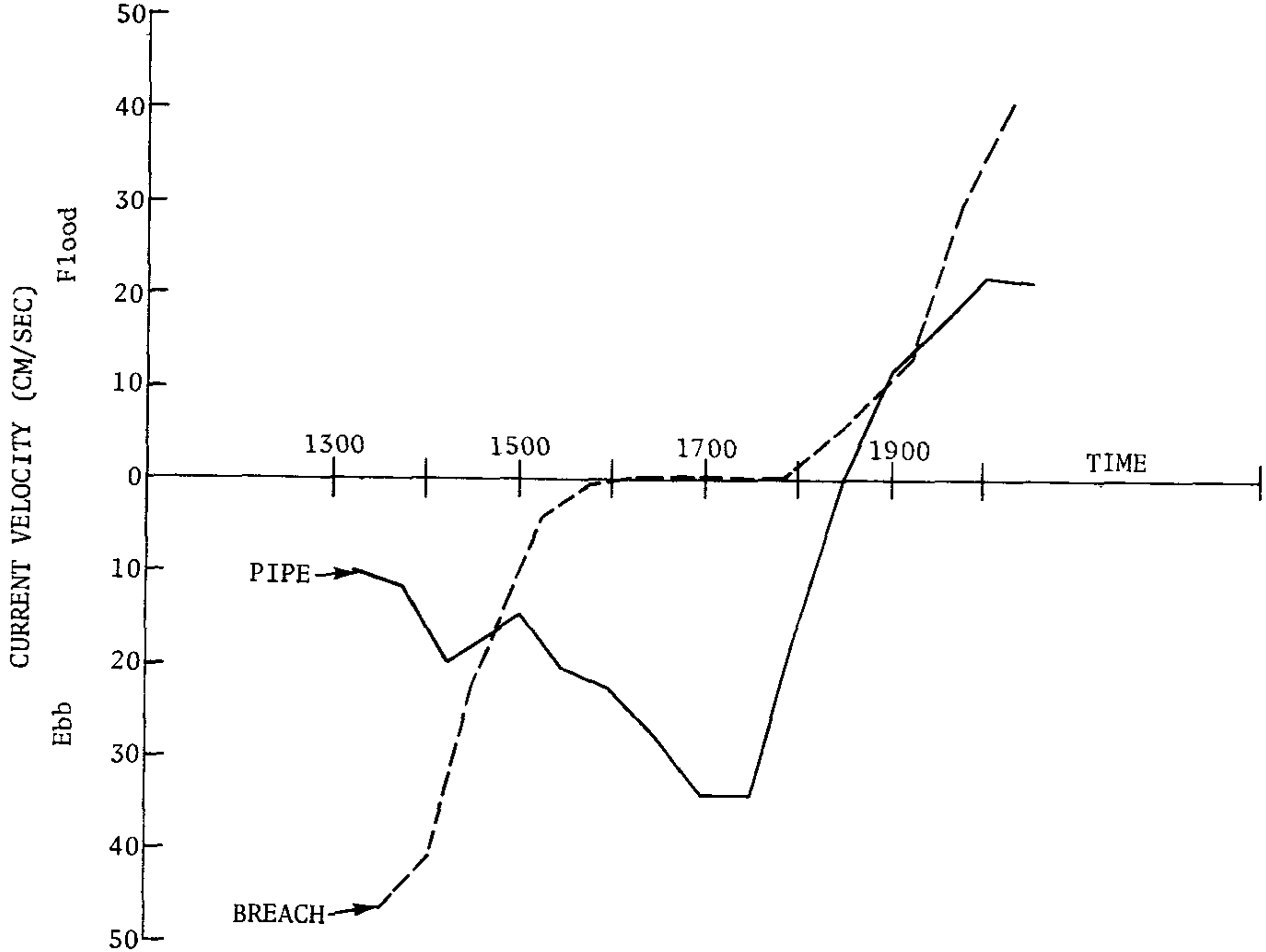

Figure 10. Detailed current velocities at the James River Artificial Habitat Development Site pipe (AP) and breach (AB) on August 6, 1976. Measurements were made every 15 minutes.

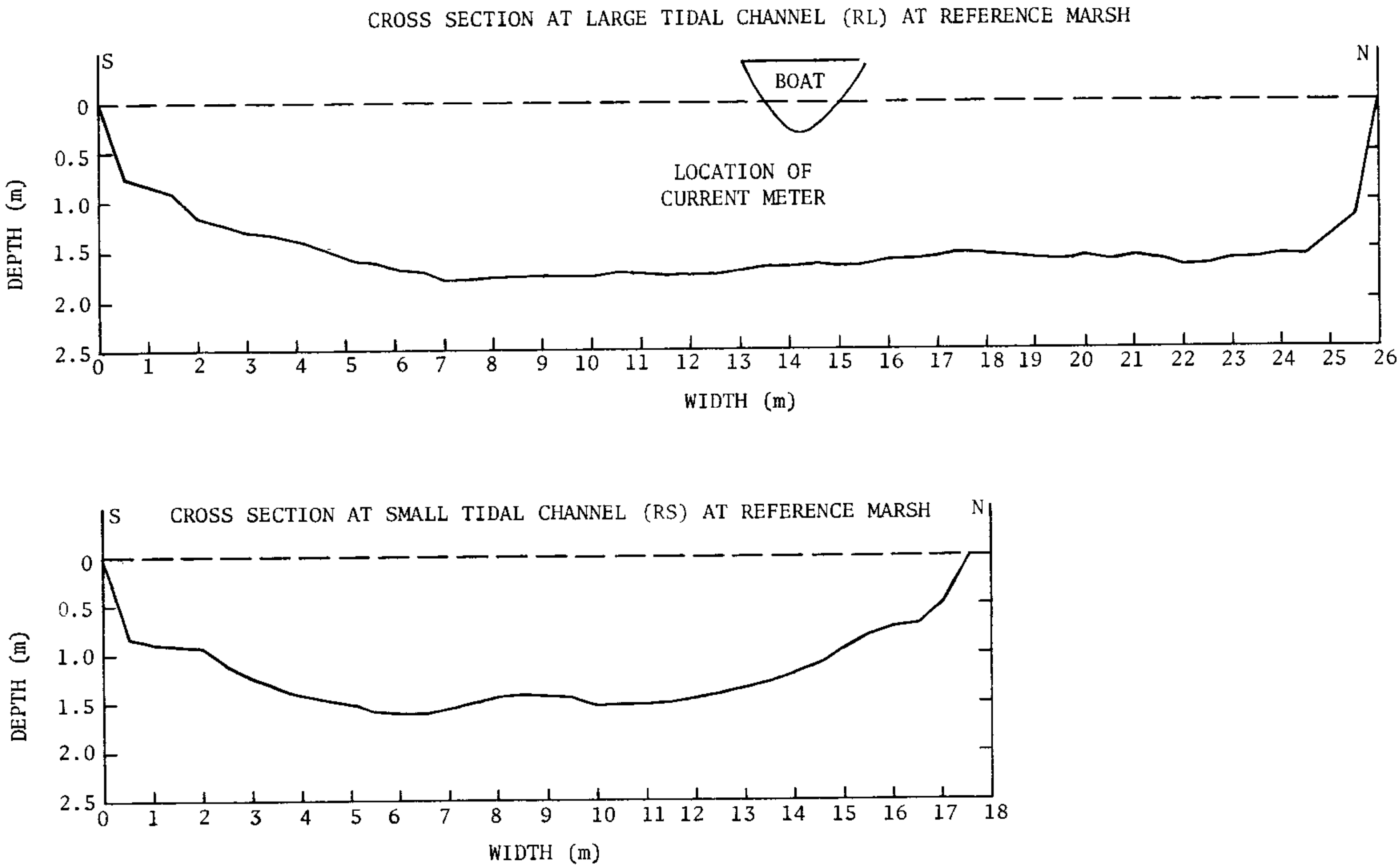

Figure 11. Cross sections of the two tidal channels at the reference marsh (see Figure 3) near Ducking Stool Point, James River, Virginia. Zero depth was low slack water at 1100 hours on August 7, 1976, which was the same as 1.0 foot tidal height at the WES tide gauge.

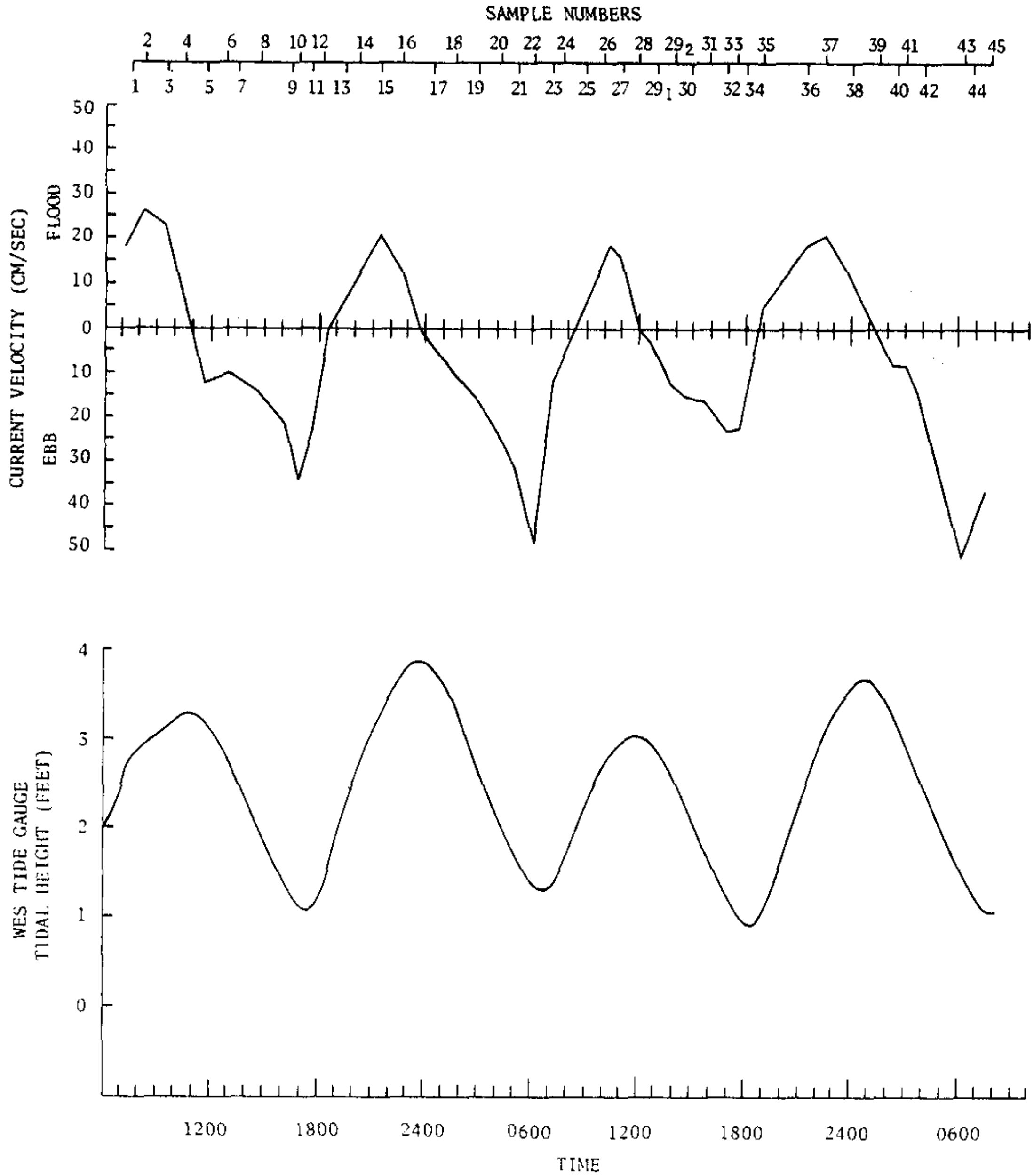

Figure 12. Sample collection times and current velocities for tidal channel AP (pipe) at the James River Artificial Habitat Development Site from August 5 to 7, 1976. Tide gauge data collected 2.7 km upstream are provided below (see Figure 1 for locations).

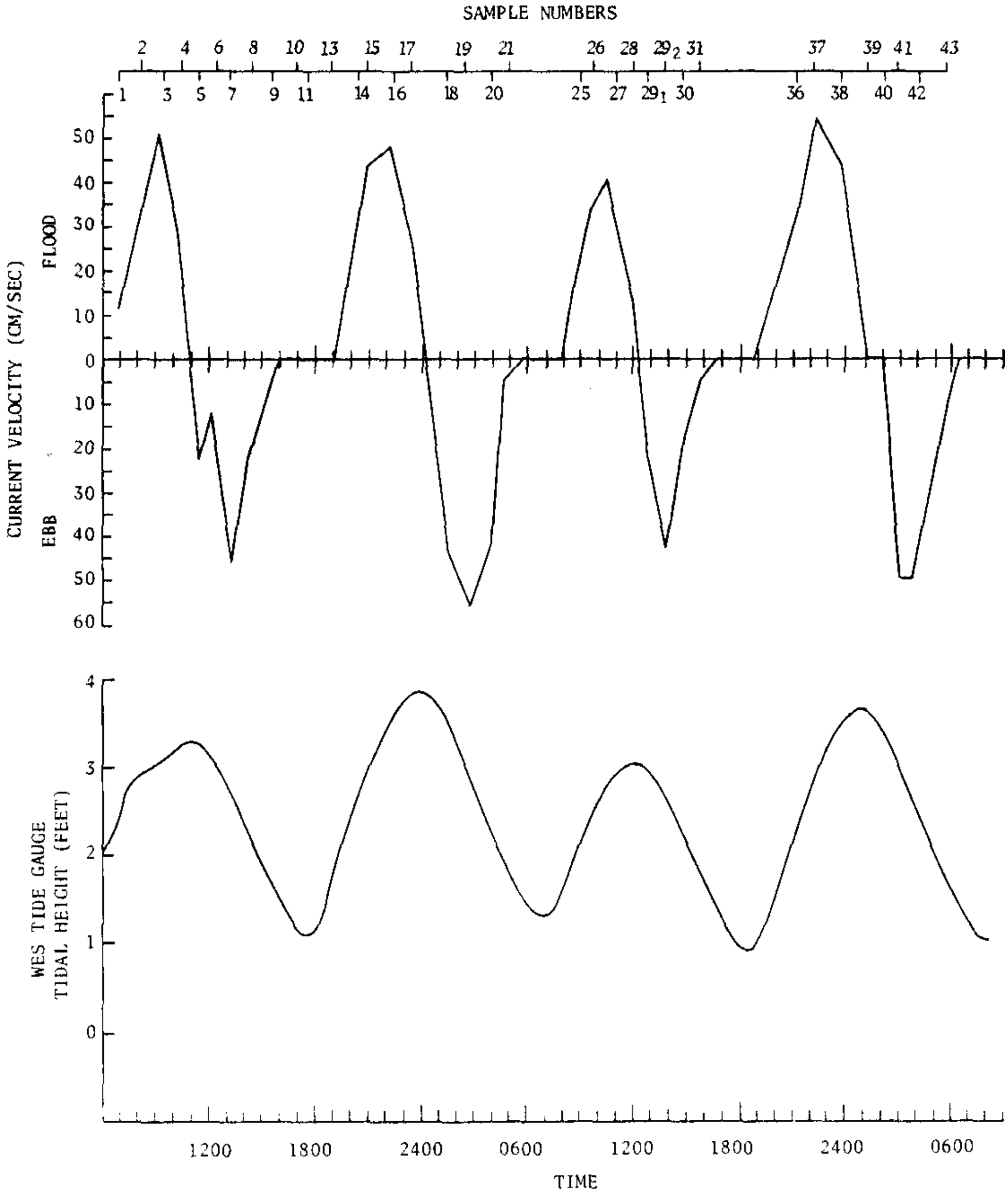

Figure 13. Sample collection times and current velocities for tidal channel AB (breach) at the James River Artificial Habitat Development Site from August 5 to 7, 1976. Tide gauge data collected 2.7 km upstream are provided below (see Figure 1 for locations).

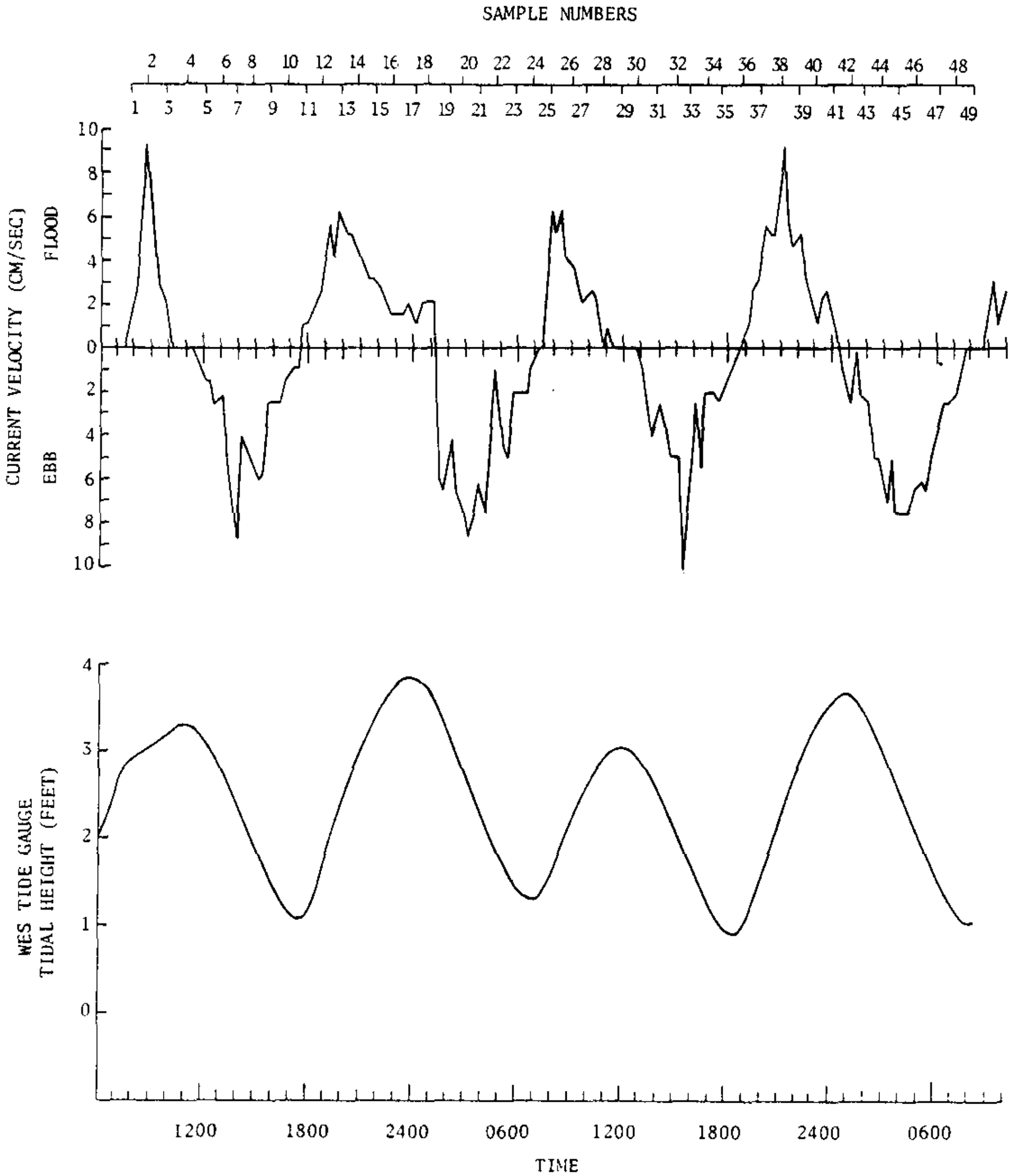

Figure 14. Sample collection times and current velocities for tidal channel RL at the reference marsh, James River, from August 5 to 7, 1976. Tide gauge data are provided below (see Figure 1). Samples from channel RS were collected at the same time as RL above, except numbers 35 and 36 were not taken and number 34 was collected at 1730 hours on August 6.

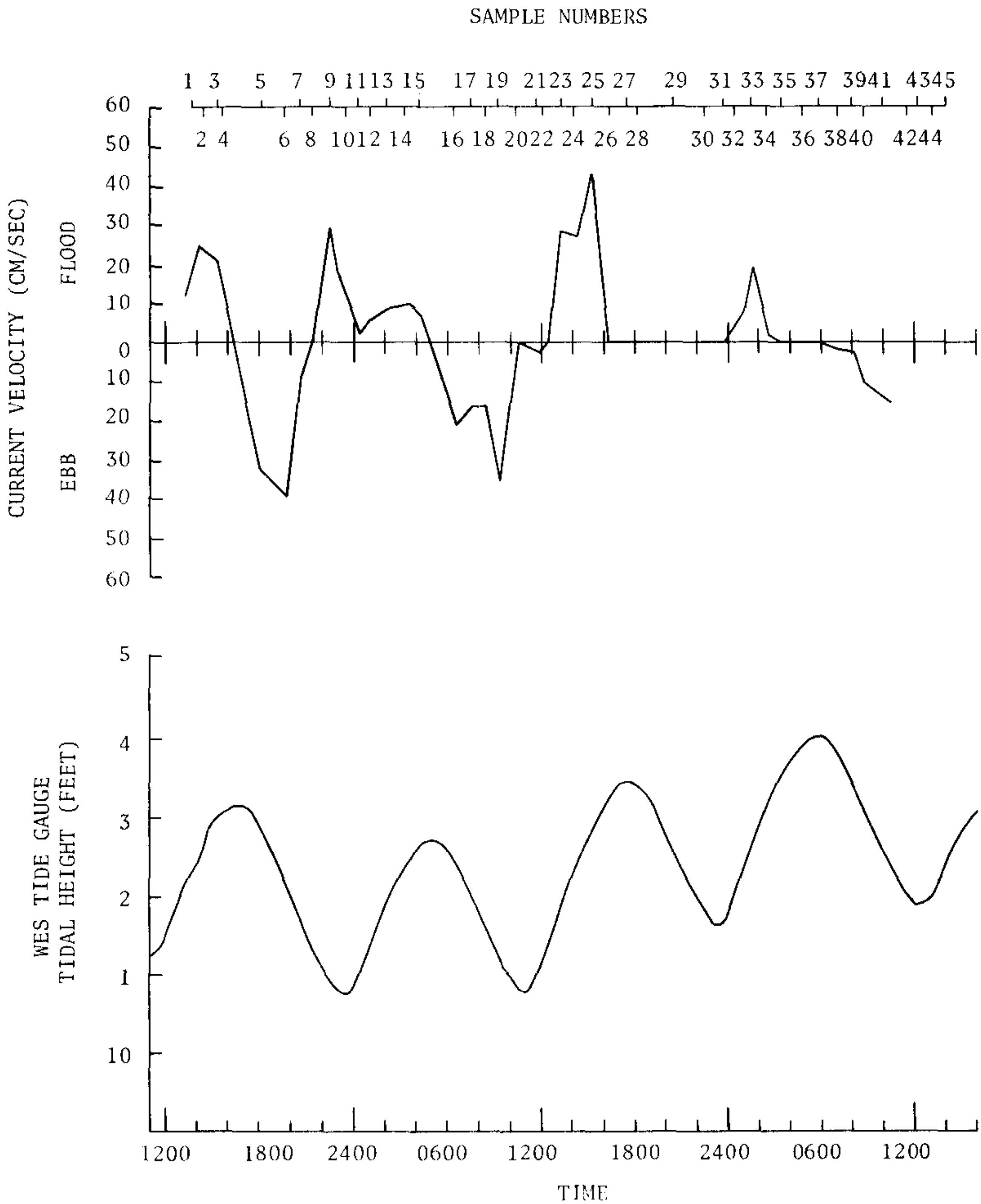

Figure 15. Sample collection times and current velocities for tidal channel AP (pipe) at the James River Artificial Habitat Development Site from January 8 to 10, 1977. Tide gauge data collected 2.7 km upstream are provided below (see Figure 1 for locations).

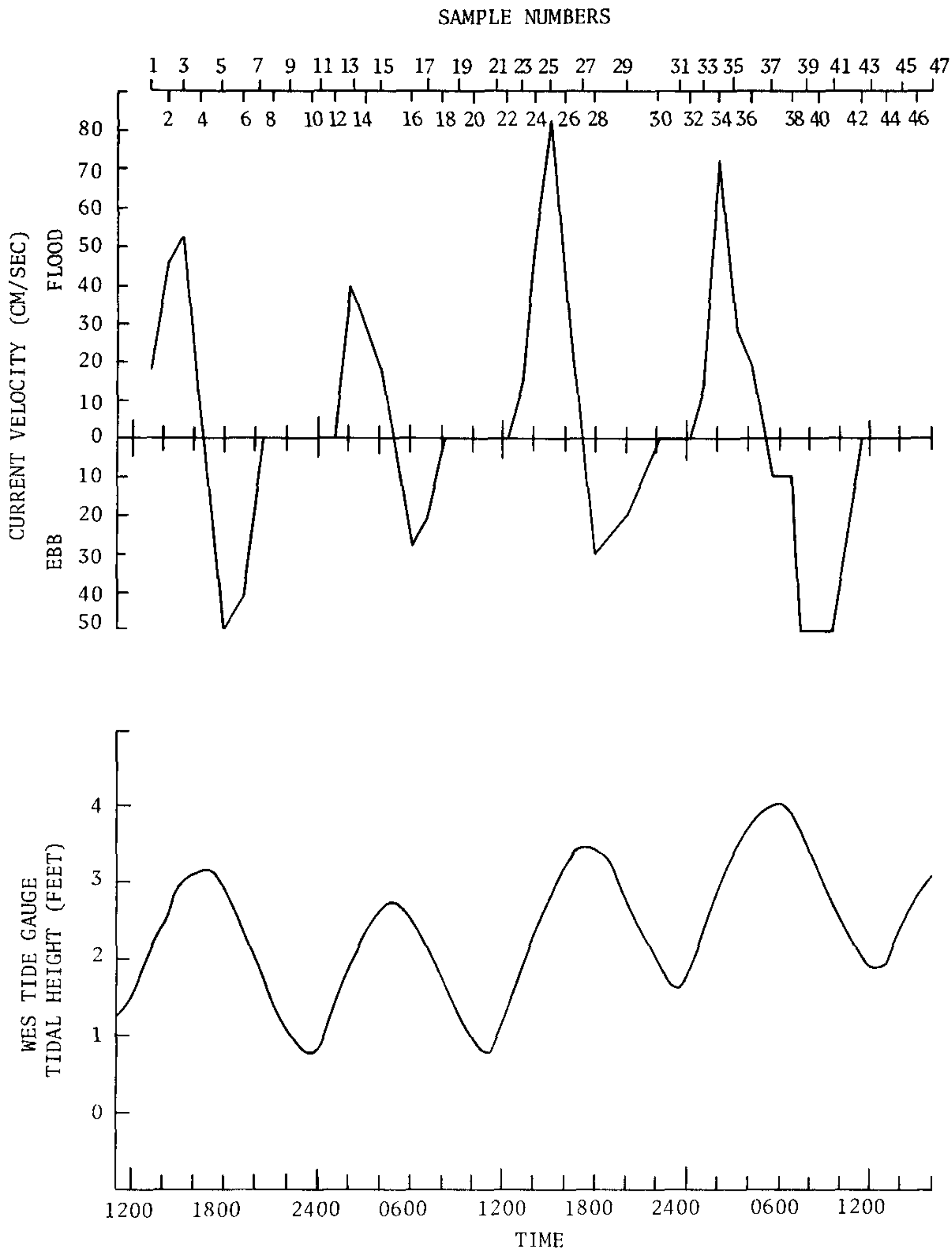

Figure 16. Sample collection times and current velocities for tidal channel AB (breach) at the James River Artificial Habitat Development Site from January 8 to 10, 1977. Tide gauge data collected 2.7 km upstream are provided below (see Figure 1 for locations).

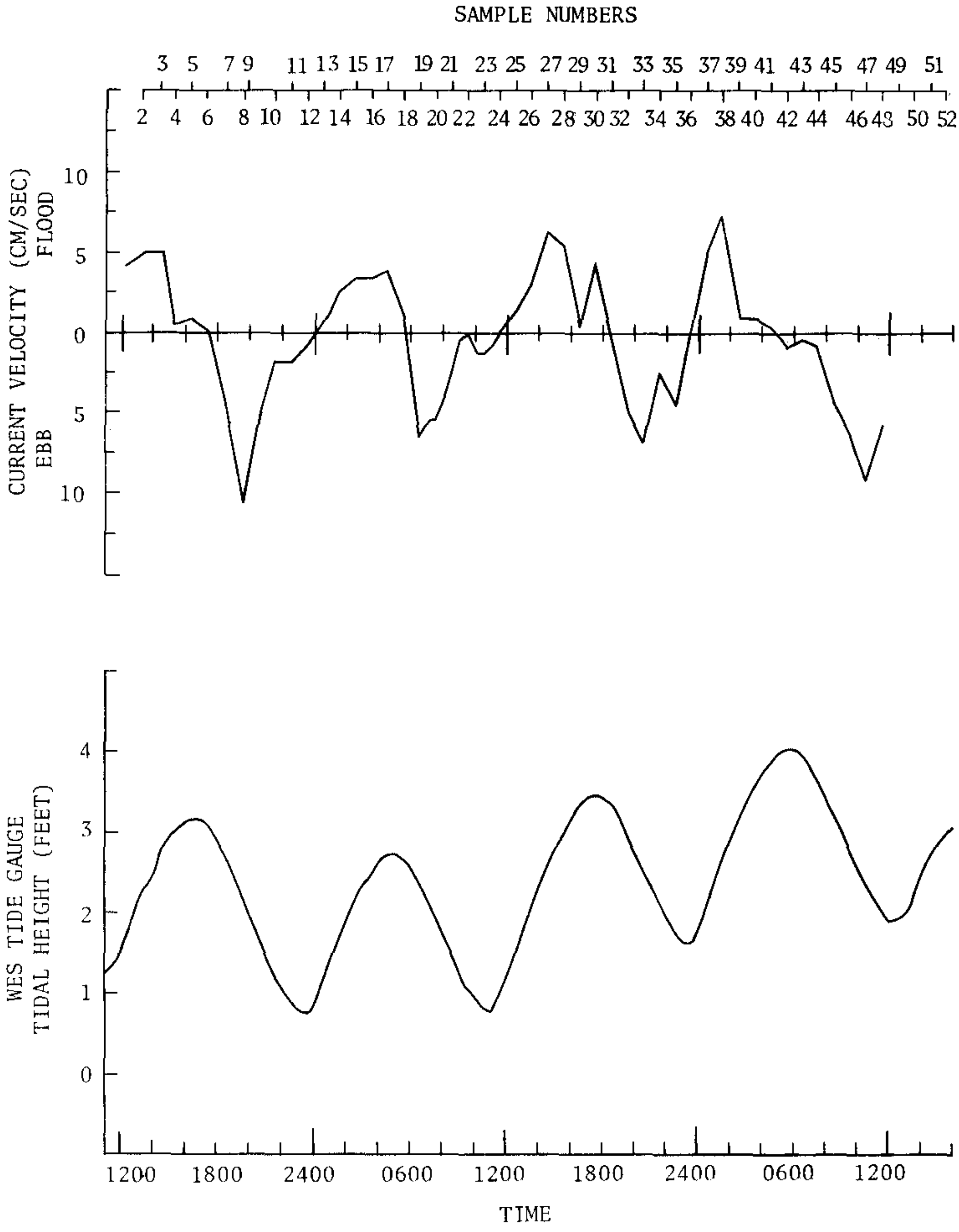

Figure 17. Sample collection times and current velocities for tidal channel RL at the reference marsh, James River, from January 8 to 10, 1977. Tide gauge data are provided below. Samples from channel RS were collected within 15-30 minutes of the time at RL shown above (see Figure 1 for locations).

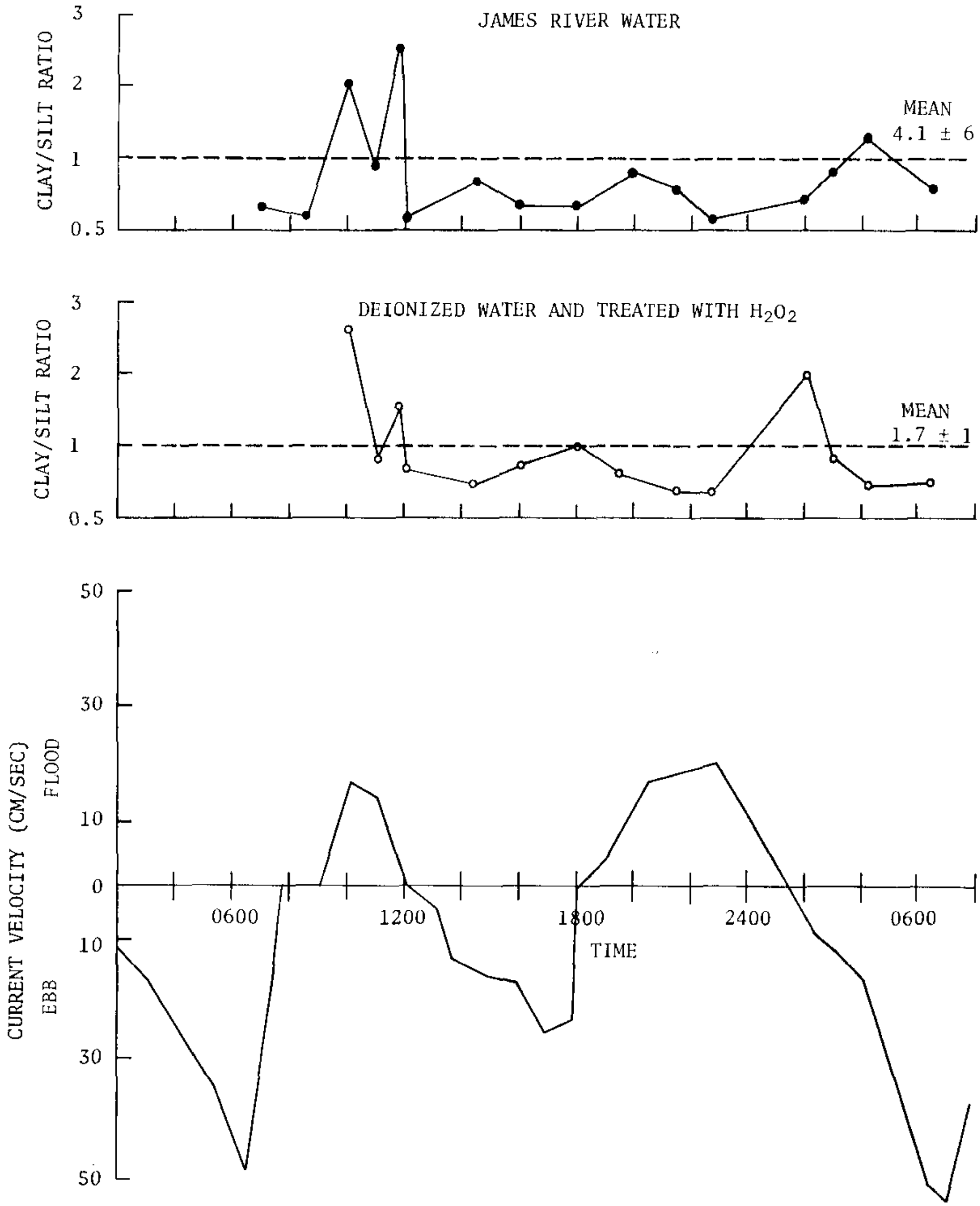

Figure 18. Naturally and artificially dispersed suspended sediments plotted as clay/silt ratios in order to emphasize the periods when the weight percent of clay (<2μ) was greater than the percent silt. Data are for August 6 and 7, 1976 at site AP (pipe), James River Artificial Habitat Development Site.

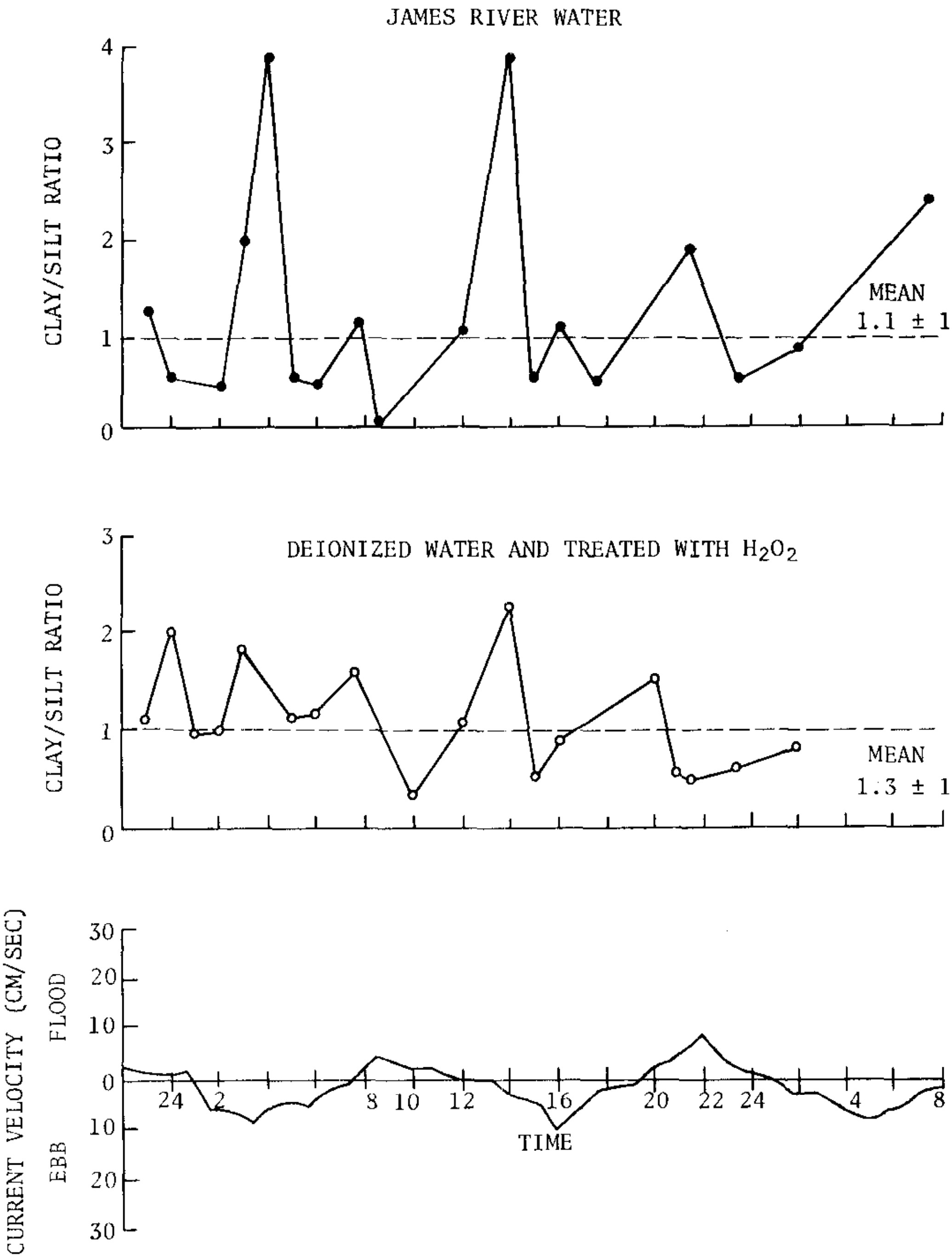

Figure 19. Naturally and artificially dispersed suspended sediments plotted as clay/silt ratios in order to emphasize the periods when the weight percent of clay (<2μ) was greater than the percent silt. Data are for August 6 and 7, 1976, at channel RS of the reference marsh, James River, Virginia.

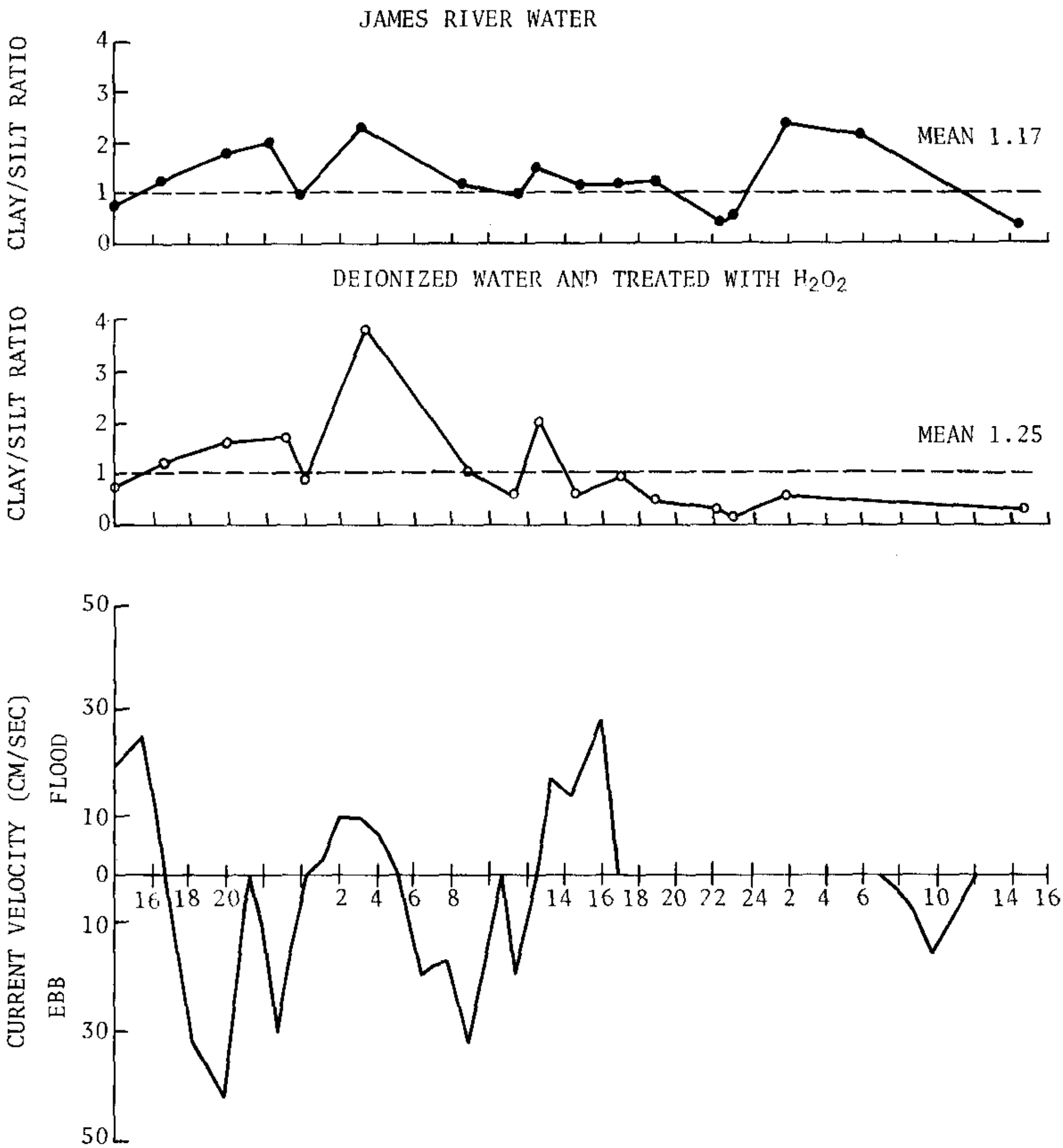

Figure 20. Naturally and artificially dispersed suspended sediments plotted as clay/silt ratios in order to emphasize the periods when the weight percent of clay (<2μ) was greater than the percent silt. Data are for January 8-10, 1977 at site AP (Pipe), James River Artificial Habitat Development Site.

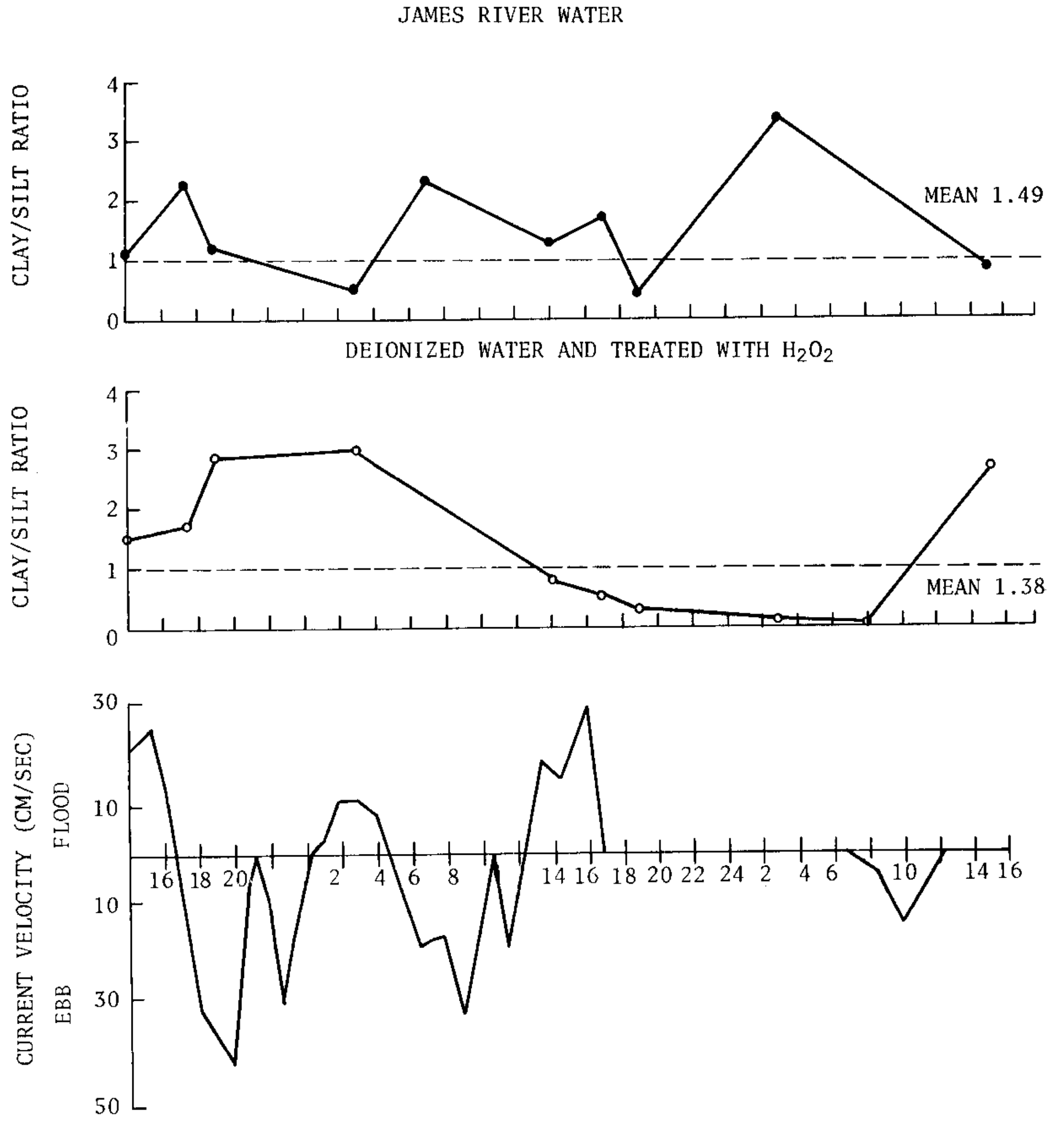

Figure 21. Naturally and artificially dispersed suspended sediments plotted as clay/silt ratios in order to emphasize the periods when the weight percent of clay (<2μ) was greater than the percent silt. Data are for January 8-10, 1977, at site AB (Breach), James River Artificial Habitat Development Site.

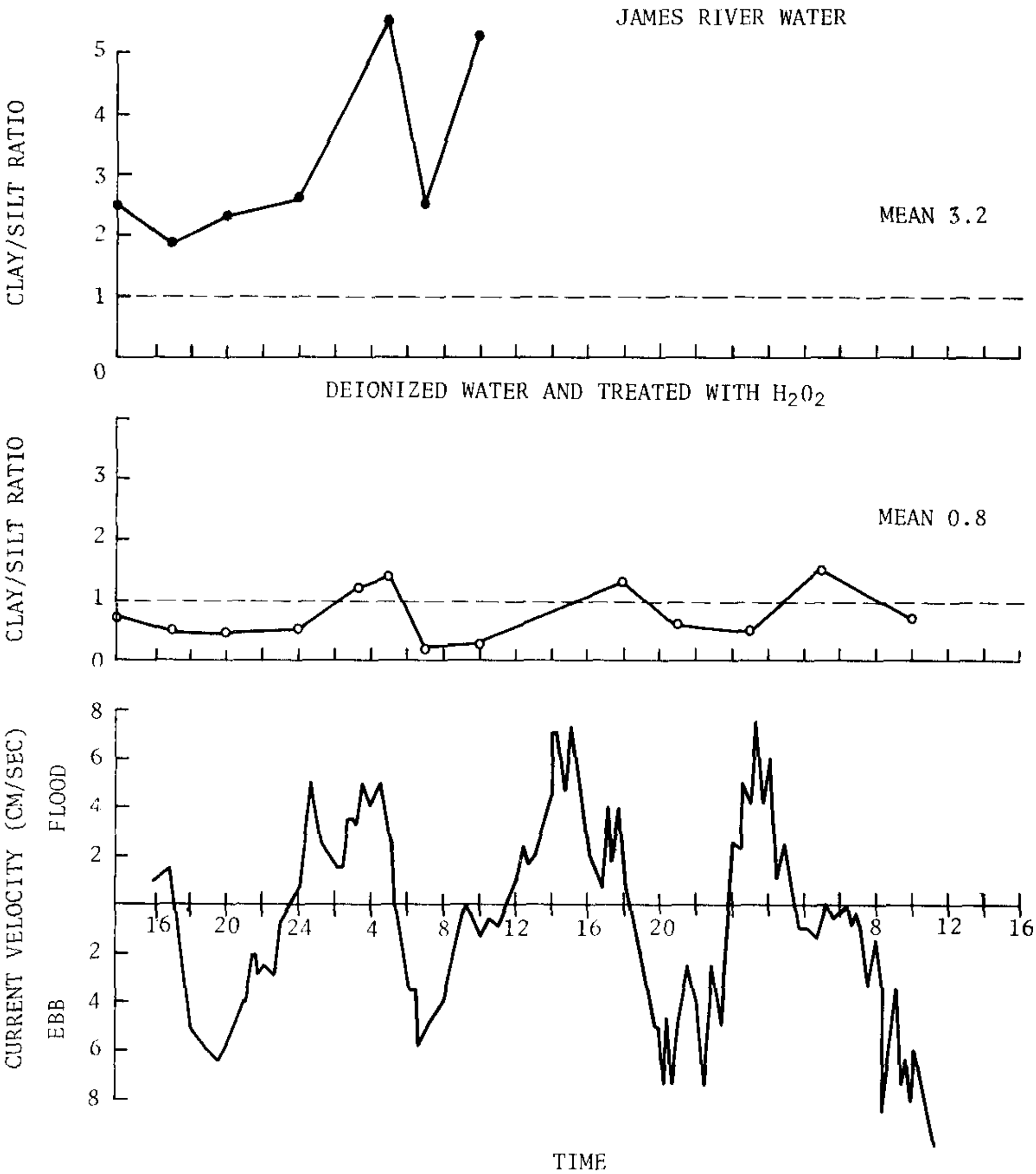

Figure 22. Naturally and artificially dispersed suspended sediments plotted as clay/silt ratios in order to emphasize the periods when the weight percent of clay (<2μ) was greater than the percent silt. Data are for January 8-10, 1977, at channel RL of the reference marsh.

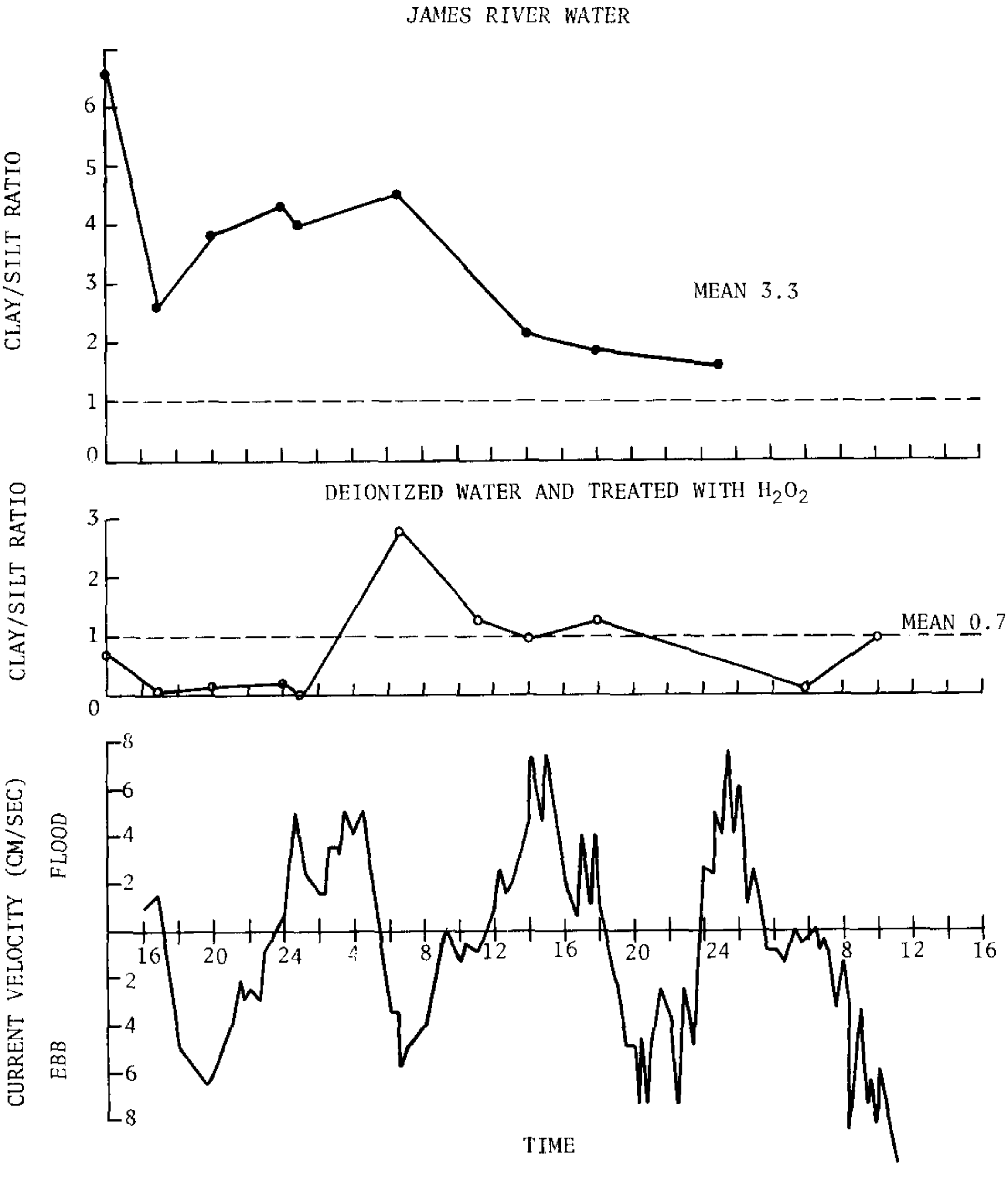

Figure 23. Naturally and artificially dispersed suspended sediments plotted as clay/silt ratios in order to emphasize the periods when the weight percent of clay (<2μ) was greater than the percent silt. Data are for January 8-10, 1977, at channel RS of the reference marsh.

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